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THE CONTROL OF WEEDS

A symposium on the prevention and eradication of weeds on agricultural land by cultural, chemical and biological means

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R. O. WHYTE

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ADDRESSES OF CONTRIBUTORS

CRAFTS, A. S. — Division of Botany, University of California, Davis, California, U.S.A.

CURRIE, G. A. — (formerly) Council for Scientific and Industrial Research, Division of Plant Industry, Box 109, P.O., Canberra City, A.C.T., Australia.
(now) Professor of Agriculture, Institute of Agriculture, University of Western Australia, Crawley, Perth, W. Australia.

DODD, Alan P. — Commonwealth Prickly-Pear Board, Laboratory, Sherwood, S.W. 3, Brisbane, Australia.

KEPHART, L. W. — Division of Cereal Crops and Diseases, Bureau of Plant Industry, U.S. Department of Agriculture, Washington, D.C., U.S.A.

LEVY, E. Bruce — Grasslands Division, Plant Research Bureau, Box 16, Palmerston North, New Zealand.

MANSKE, R. H. F. — Division of Chemistry, National Research Council, Ottawa, Canada.

MILLER, D. — Cawthron Institute, Nelson, New Zealand.

MONTEITH, John, Jr. — U.S. Golf Association (Green Section), Box 73 Benjamin Franklin Station, Washington, D.C., U.S.A.

PAVLYCHENKO, T. K. — University of Saskatchewan, Saskatoon, Sask., Canada.

RADEMACHER, B. — Institut für Pflanzenschutz der Landw. Hochschule, Hohenheim bei Stuttgart, Germany.

RAYNOR, R. N. — Division of Botany, University of California, Davis, California, U.S.A.

STEYN, D. G. — Division of Veterinary Services, P.O. Onderstepoort, Pretoria, South Africa.

INTRODUCTION AND SUMMARY

The weeds of arable land, grassland, orchards and other types of agricultural lands rank with fungous diseases and insect pests as one of the chief causes of reduction in crop yields, carrying capacity of pastures, purity of seed stock and the general economic return from farming enterprises of many kinds. Research on weed problems has been carried on to a varying degree in certain countries for many years, but there has recently been a marked increase in the attention given to the question, particularly in the British Commonwealth of Nations and the United States of America. Extensive programmes of research on the control of weeds by cultural, chemical or biological means have been commenced in these and other countries, and important results are rapidly becoming available.

It was considered that the present moment would be opportune for the publication of a symposium setting forth the various aspects of the problem as affected by the different types of agriculture in the countries chiefly concerned, together with the practices characteristic of those countries, and the preliminary results of the extensive research programmes which have been instituted.

This Bureau was extremely fortunate in being able to arrange for the full co-operation of the specialists in the different countries best qualified to discuss their own research and practices, and feels highly honoured at being able finally, in spite of unsettled conditions, to produce such a comprehensive picture of the present position with regard to weeds as given by the articles contained in this Bulletin.

There are two gaps in the original scheme ; one article from India was withdrawn, as was also the chief article from South Africa. The latter was to be contributed by A. C. Leemann, but the fact that the author had just obtained indications of certain important new results made the writing of a contribution of the problem in South Africa impossible at that time. These results will presumably be published in due course and will be given appropriate prominence in *Herbage Reviews*.

This Bulletin starts with two articles from Canada. In the first, T. K. Pavlychenko discusses the origin of the Associate Committee on Weeds, and deals with the preliminary findings at the Research Laboratory on Plant Ecology at the University of Saskatchewan, where attention has been devoted chiefly to competition between weed and crop plants, to the nature of the root systems of various plants, and to studies of depth of germination of weed and crop seeds.

The second article from Canada is a short contribution from R. H. F. Manske on the question of chemical analysis as an aid to the classification of poisonous plants. This paper and the final one, by D. G. Steyn, South Africa, indicate that the poison plant problem is an important offshoot of the weed problem in pastures and range, which must always be borne in mind. Steyn also refers to two most important pasture problems, namely, hydrocyanic poisoning and photosensitization.

Following the two from Canada are three from the United States of America. According to L. W. Kephart the most urgent weed problem of the moment in the United States is that of the persistent, aggressive, destructive, chiefly perennial species for which there is no adequate control. During the past fifteen to twenty years, these have become a real and growing menace; about 6,000,000 acres of excellent farm land west of the Mississippi River are so thoroughly occupied by noxious weeds that continued crop production is seriously menaced. With authority from Congress, given in 1935, the Bureau of Plant Industry has organized a series of weed research stations in eight States. Among these the Californian project, which involves the technical aspects of chemical weed-killers, is covered in the article by A. S. Crafts and R. N. Raynor; " since the failure, in certain situations, of the older cultural and cropping methods, weed control by chemistry is advancing, especially in the newer districts which practise large scale farming, machine production and irrigation." These authors deal with contact and translocated sprays and soil treatments.

John Monteith, Jr., states that " the control of weeds continues to be one of the most perplexing problems of the turf culturist," and discusses the effects of maintenance methods, fertilizers, mowing height and frequency, and chemicals on the weed species of turf.

B. Rademacher discusses seed cleaning, crop rotation, relative shade effects of the weed and crop plants and the use of corrosive fertilizers and special chemicals in the control of weeds. The chemical section is interesting, particularly when compared with the American outlook expressed by Crafts and Raynor.

Two articles are contributed by Australian specialists. G. A. Currie describes the research carried out by Federal and State Officers on life history studies, chemical and biological control, and control by pasture management, the use of smothering plants, cultivation and crop rotation. The most outstanding success yet achieved from the use of biological control, the eradication of prickly pear by *Cactoblastis cactorum*, is described by A. P. Dodd.

The application of the same entomological technique to certain weed problems in New Zealand is outlined by D. Miller. The only article dealing exclusively with pasture weeds is contributed by E. Bruce Levy, who is concerned with the relative shading and competitive influence of pasture species on weeds, and the effect and use of the grazing animal in the encouragement or suppression of weeds of grassland.

T. K. Pavlychenko Canada

INVESTIGATIONS RELATING TO WEED CONTROL IN WESTERN CANADA*

GENERAL CONSIDERATIONS

Canada is a large country, its territory extending over 84° of longitude and 42° of latitude. This area embraces roughly 3,694,863 square miles of the surface of North America, and is only slightly less in size than the entire territory of Europe.

It is estimated that approximately 140,887,903 acres of Canadian soil are utilized at the present time. This includes the land under cultivated field crops, pastures, gardens and farmsteads. In all these areas weeds are present, interfering materially with easy handling of the soil, and causing a reduction in quantity and quality of crop yields and in the net income from agriculture.

The low annual precipitation of the grain-growing sections of Western Canada makes it imperative for the farmer to follow a system of continuous grain farming. This system allows weeds to enter the land easily, and, in the absence of inter-tilled crops and long term pastures, offers only limited opportunity for the farmer to adopt control measures. The plains produce annually great quantities of the famous hard red spring wheat, of high milling, baking and blending qualities, which crop has made agricultural Canada so well known.

According to Canadian statistics, of 57,662,550 acres under cereal crops in 1937, wheat alone occupied 25,289,000 acres. A ten-year average annual wheat production in Canada is 361,486,300 bushels (**3**). In 1927 eight per cent, or 31,411,000 bushels of the total production was classified " unmarketable " and consisted mostly of dockage (**4**). This does not take into account the much larger quantity of weed seeds which were undoubtedly shattered on the ground. It should be remembered also that to the loss in crop value should be added the additional loss caused by the increased cost of cultivation of the weedy land and the extra expense of cutting, threshing, transportation and cleaning of the grain.

The extensive area of the Dominion, its ever-changing topography, and the presence of large bodies of water at the coasts and inland, cause great differences in regional climates, soil types and vegetation. For these reasons the weed problem in Canada is of great complexity.

Certain weeds well adapted and prevalent in one ecological zone with definite soil type may be scarce or totally absent in others. Similarly, certain methods of weed control may prove effective under dry conditions in the grassland zone, but lose their value in a more humid region. Thus, it is impossible in a brief article to give a

*Contribution from the Research Laboratory of Plant Ecology, University of Saskatchewan, with financial assistance from the National Research Council of Canada and the Dominion Department of Agriculture.

comprehensive outline of the specific weed control measures practised in different agricultural districts of the Dominion. It was felt, however, that a brief account concerning the organization of weed research in this country, together with some results from projects dealing with the fundamental biological phases of the weed problem, would give information of interest to those engaged in this line of research within the British Commonwealth and elsewhere.

While experimental work in weed control has been carried on in Canada for many years, new impetus was given to weed research as the result of a Provincial conference called at Regina, Saskatchewan, in 1929. The delegates unanimously emphasized the gravity of the weed situation, particularly in Western Canada, and recognized with equal clarity the need for systematic weed research to provide scientific information to cope with the problem.

(a) Associate Committee on Weed Control

In the autumn of 1929, the National Research Council took the lead in organizing an "Associate Committee on Weed Control." This was initiated at a Conference convened at Edmonton, Alberta. Members of the Committee were selected from representatives of the Dominion and Provincial Departments of Agriculture, the National Research Council of Canada, Provincial Universities, and important business interests. Its purpose was to assign research projects to various Universities and to co-ordinate results on weed research in the Dominion (**13**). Since that time the results of work done at Dominion and Provincial Institutions have been reported annually to the Committee. Much attention has been given to fundamental biological studies of weed and crop plants, and to methods of destroying weeds by chemical and cultural methods. The various papers published under this Committee have been compiled in a volume (**5**). Some information still remains unpublished in mimeographed form (**19**), and certain recent articles do not appear in this volume (**8**).

(b) Associate Committee on Weeds

In 1935 this Committee was further re-organized in order to effect a still greater co-ordination between the weed work carried on by the Dominion Department of Agriculture, the National Research Council and various Universities throughout Canada. Since that time the Committee has operated under the joint jurisdiction of the Dominion Department of Agriculture and the National Research Council of Canada. Its scope of work was somewhat broadened, and the name changed to "Associate Committee on Weeds." The Committee places increasing emphasis upon the fact that most weeds are adapted to definite ecological regions and, therefore, should be studied in close relation to the climatic and soil conditions of the areas in which they occur.

(c) The System of Dominion Experimental Farms

In 1886 the Experimental Farm Stations Act was adopted in Canada, whereby a number of agricultural research institutions were established throughout the Dominion. The programme of the Dominion Experimental Stations embraces

practically all phases of agriculture, including the weed problem. During the earlier period of their history, the Experimental Stations were primarily concerned with practical measures of weed control, based on observations and empiric trials. Gradually however, specific projects on weed research were introduced. At the present time the general trend in this work is to classify the agricultural land into climatic zones, and to study the weed flora of each region in relation to local conditions.

(d) Research Laboratory of Plant Ecology

In 1930, the National Research Council granted funds for establishing a Weed Research Nursery at the University of Saskatchewan, the purpose being to carry on fundamental biological studies with important weeds and crops in Western Canada. In 1936, the Dominion Department of Agriculture gave additional financial assistance to this work, and in keeping with an expanding programme the name was changed in 1938 to the " Research Laboratory of Plant Ecology," with a study of weeds and crop plants in their complex relationship to climate and soil and to one another as its objective.

SOME RESULTS OF WEED INVESTIGATIONS

Some of the significant findings from studies conducted at the Research Laboratory of Plant Ecology during the last few years will now be reviewed.

(1) Competition Between Weed and Crop Plants

(a) Heavy versus normal rate of seeding

In agricultural literature references are frequently made to "clean" and "weedy" land. In practice, however, there is no such thing as a "weed-free" soil. Careful observations and records obtained at Saskatoon over a period of six years from fields reputed as clean, reasonably clean and weedy fully confirm this contention. When these fields were left for one season without cultivation for weed control, all produced heavy stands of volunteer growth, fully sufficient to exhaust completely the available moisture from the soil. For this reason they may all be justly classified as weedy land. When fields with similar infestation were sown to various crops at different rates, and the counts on weed-crop population taken at the early stages of growth, they again appeared as decidedly weedy. Counts taken from the same areas at harvest show at once, however, that certain fields were entirely free of weeds, others contained only a few weeds, while still others were extremely weedy.

Data on the effect of normal and heavy rates of seeding are given in Table 1 as evidence of the result of competition between weeds and crop plants. Each figure in this table presents an average from sixty sample areas counted in six successive years at Saskatoon, Saskatchewan.

It is evident that the initial percentage population of weed seedlings five days after emergence was considerably less in certain plots because of the heavier rate of seeding (*not due to competition*) ; that toward maturity, *owing to competition*, the number of weeds was gradually reduced by all crops except flax ; and that this reduction was most rapid in (1) barley fields sown heavily, followed in order by (2) barley

Table 1.—Effect of normal and heavy rates of seeding on the weediness of different crops.

No. of days from emergence.	Rate of seeding.	Number of plants per square yard.											
		Wheat	Weeds		Oats	Weeds		Barley	Weeds		Flax	Weeds	
			No.	Per cent.		No.	Per cent.		No.	Per cent.		No.	Per cent.
5	Normal	252	118	46.8	224	114	51.3	226	68	30.1	313	140	44.7
	Heavy	424	99	23.3	402	111	27.5	357	36	10.1	411	126	30.7
22	Normal	321	72	22.4	369	88	23.8	341	60	17.6	357	161	47.9
	Heavy	523	54	10.3	457	72	15.7	443	23	5.1	477	143	29.9
40	Normal	332	68	20.4	374	62	16.5	384	33	8.5	223	194	86.9
	Heavy	534	3	.5	461	39	8.4	446	0	0	386	158	40.9
80	Normal	335	54	16.1	376	60	16.1	384	16	4.1	184	238	129.3
	Heavy	534	1	.01	462	36	7.7	446	0	0	282	172	60.9

fields sown at the normal rate, (3) wheat with heavy seeding, (4) wheat at the normal rate, (5) oats with heavy seeding, and (6) oats at the normal rate. A reduction of the weed population did not take place in the case of flax ; instead, the numbers of weed plants gradually increased toward maturity.

Figures 1 to 4 illustrate the amount of wild mustard (*Sinapis arvensis*) in fields of barley, wheat, oats and flax where infestation was the same and other growing conditions as similar as possible.

(b) Amount of dry matter per unit area

The number of weed plants per unit area, however, is not the best indication of the extent of injury to the crops. Frequently weeds are very numerous at the early seedling stage, but totally disappear during the later part of the season, leaving crops practically free of weeds at harvest. On the other hand, a few luxuriant weed plants in a square foot surviving to maturity may take almost exclusive possession of the land. Therefore the amount of dry matter produced by weeds in relation to that of crop plants per unit area affords a much better criterion of damage. Data to illustrate this point, obtained from controlled experimental plots, are given in Table 2.

Table 2.—Percentages of dry matter produced by weeds grown in competition with various cereal crops (three-year test)

Competing Species	Barley	Spring rye	Wheat	Oats	Flax
Crops	100	100	100	100	100
Wild oats	4	10	77	45	35
Wild mustard	4	39	43	94	443

FIG. 1.

FIG. 2.

FIG. 3.

FIG. 4.

FIG. 1.—Barley in competition with wild mustard.
FIG. 2.—Wheat in competition with wild mustard.
FIG. 3.—Oats in competition with wild mustard.
FIG. 4.—Flax in competition with wild mustard.

FIG 5.

FIG. 5.—Amount of dry matter produced by hare's ear mustard (*Conringia orientalis*) in 4 ft. rows grown in competition with (from left to right) wheat, rye, oats, barley and flax.

FIG 6.

FIG. 6.—Amount of dry matter produced by redroot pigweed (*Amarantus retroflexus*) in 4 ft. rows grown in competition with (from left to right) wheat, rye, oats, barley, barley and flax.

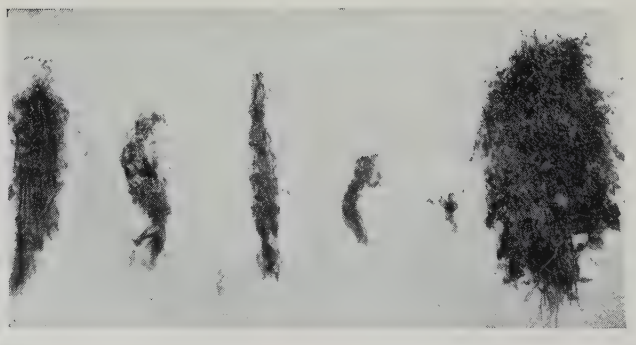


FIG. 7.

FIG. 7.—Amount of dry matter produced by wild buckwheat (*Polygonum convolvulus*) in competition with (from left to right) wheat, rye, oats, barley, barley and flax.

The grain yields of these crops, expressed in percentages of the controls, were reduced due to the presence of the wild oats and wild mustard in their stands (Table 3).

Table 3.

Weeds	Barley	Spring rye	Wheat	Oats	Flax
Wild oats	15.3	28.8	28.1	45.7	85.1
Wild mustard	25.6	33.5	30.8	43.0	84.5

Results obtained by the Provincial Department of Agriculture in Saskatchewan (**8**) from extensive trials on the effect of heavy seeding upon the yield of crops under heavy weed infestation are quoted in Table 4.

Table 4.

Crops	No. tests	No. years	Yield in bushels per acre Seeding: Light	Yield in bushels per acre Seeding: Heavy	Average differences in bushels
Wheat	49	5	12.6	15.2	2.6
Oats	31	4	36.1	41.4	5.3
Barley	34	3	21.7	27.1	5.4

The amount of dry matter produced by various weeds under similar infestation, and in competition with different crops, is illustrated in figures, 5, 6 and 7.

These are some of the empiric results showing that the same weeds react very differently under similar infestation, climatic and soil conditions when growing with different crops, or if the latter are sown at different rates. The reasons for the variations are not well understood, but they undoubtedly lie chiefly in the biological capacity of the plants to utilize the environment more efficiently, and in their ecological adaptation to the existing soil and climatic conditions.

(c) Readiness and uniformity of germination

Among other biological characters, readiness and uniformity of seed germination under adverse conditions are important for the success of any plant in competition with other species (**20**). These features of germination give the plants an opportunity to occupy the space more rapidly and more completely before other species, with slower and lower rates of germination, appear above the surface in sufficient numbers. During a period of three years, from 1935 to 1937 inclusive, thorough tests have been made under ordinary field conditions to determine the rate of germination of the seeds of twelve common weeds and fourteen cereal crops (Table 5).

Table 5.

Period of test in days	Percentage germination	
	12 common weeds	14 cereal crops
0 to 5	26.2	73.0
6 to 10	11.2	10.2
11 to 22	10.5	1.6
Total	47.9	84.8

The first line in table 5 shows that, under similar field conditions, the cereals as a group gave 73 per cent of the germinated seeds in the first 5 days of the test. Twelve weeds, however, produced only 26.2 per cent over the same period. During the next 5 days the crops practically reached the limit of their germination capacity, while the weeds continued to germinate slowly until the 22nd day of the test. Due to this fact the crops produced a dense and uniform stand in a few days, thoroughly occupied the soil with their roots, covered the surface with top growth, and left little chance of survival for the weeds which germinated at later dates.

(d) Assimilation leaf surface

Another biological factor which plays a decided part in determining the competitive efficiency of a species is the extent of the assimilating leaf surface per individual plant at different stages of development. The number of stomata per unit area of the leaf surface accentuates the importance of this character. Plant species which possess a large leaf surface with many stomata per unit area are capable of synthesizing plant building materials at a greater rate, and therefore grow much more rapidly than those with less leaf surface and fewer stomata.

It may be of interest, therefore, to give some data to this effect, concerning at least the most important weeds and crops (Table 6). These show that, at the five-day stage, all cereals had much larger leaf surfaces than the weed plants. The numbers of stomata per plant were also much higher in cereals than in weeds, with the single exception of wild mustard. At the blooming stage, on the other hand, all weeds had far surpassed the crops, both in extent of leaf surface and in number of stomata per plant. This certainly gives at least one fundamental reason why weed plants are smothered with ease by a dense growth of cereal crop in the early stage of their development, and why the same weeds, if they survive through this critical stage, choke the crops during the later part of the season (**20**).

(e) Plant roots

A greater readiness and uniformity of germination gives any species a definite advantage in competition with other plants of slower and lower rates of germination.

Table 6.

Plants:	Total leaf surface sq. cm.	No. of Stomata per plant	No. of Stomata per sq. cm.	Total leaf surface sq. cm.	No. of Stomata per sq. cm.	No. of Stomata per plant (millions)
	Five days after emergence:			At blooming stage:		
Avena fatua	6.4	4,700	30,300	260	4,800	1.2
Sinapis arvensis	2.5	31,800	79,800	7,300	66,500	490
Conringia orientalis	1.1	20,900	23,000	650	18,700	52
Amarantus retroflexus	0.7	13,600	9,600	1,400	29,900	42
Axyris amarantoides	0.5	4,500	2,300	3,600	20,900	74
Marquis wheat	8.6	4,700	40,300	140	4,900	0.7
Hannchen barley	18.6	3,500	64,300	300	4,100	1.2
Banner oats	10.2	4,200	43,200	140	4,400	0.6
Prolific spring rye	13.1	4,900	63,700	150	4,700	0.7

This factor becomes of importance before the young seedlings emerge above the surface. The germination itself initiates active growth, but is incapable of supporting it. The assimilating leaf surface, on the other hand, is closely associated with plant nourishment and synthesizing processes, but it assumes this paramount function only after the young plants have emerged and developed a considerable amount of foliage. The root begins to play its part in the life of plants between these two important stages. It is the first organ to support new life developing from the seed. Plants with defective roots die before emerging above the surface. Those with weak root-systems live for some time and perish before maturity. Only individuals with healthy and strong roots produce a luxuriant top growth and mature fruit (**21**). This statement is based on the most careful analyses of the root systems of many thousands of plants grown under ordinary field conditions, under irrigation, and in the greenhouse, at Saskatoon.

These quantitative studies of root systems of weed and crop plants indicate that, at least in areas with arid climates, the most severe competition between weed and crop plants centres around the supply of available soil moisture to the plants, this being the limiting factor in crop production. Competition begins as soon as the root system of one plant invades a feeding area of another, and usually takes place long before tops are developed sufficiently to exert a serious competition for light. Therefore, in dry climates, roots actually decide the success or failure in competition between species otherwise equally adapted to a region. The top growth is then developed in proportion to the extent of the root system (**14**).

The distribution of roots and the depth of their penetration are also important, particularly where two or more unrelated species grow in close association. Some

comparative results on the extent of the root systems and yields of barley and wheat, both grown free and in competition with wild oats (*Avena fatua*) and common wild mustard (*Sinapis arvensis*), are given in Table 7.

Table 7.

Age in days after emergence	Standards	Length of roots in inches and percentages				
		Cereal check	Competition		Competition	
			cereal	wild oats	cereal	wild mustard
Barley 5	inch	112	98	16	99	22
	percentage	100	87	14	88	20
22	inch	5849	4200	752	3814	2850
	percentage	100	72	13	65	49
40	inch	9865	7232	1974	6446	4632
	percentage	100	73	20	65	47
Yield at maturity	percentage	100	85	—	74	—
Wheat 5	inch	68	56	23	57	28
	percentage	100	82	33	84	41
22	inch	3534	2820	1725	2711	4118
	percentage	100	80	49	77	116
40	inch	5342	4169	2046	3449	6053
	percentage	100	78	38	65	117
Yield at maturity	percentage	100	72	—	69	—

These data reveal several points of considerable practical significance. First, they show that at the early seedling stage the root systems of the two crops taken from the control and competition plots are nearly equal in size, and much greater than those of the weeds competing with them. Secondly, they demonstrate that as the season progressed, the size of the root systems of crop plants excavated from the competition plots gradually decreased in comparison with the controls. Thirdly, these results indicate that crop yields decrease almost exactly in proportion to the degree of reduction of the root systems, due to competition with weeds. Finally, they prove that the weeds which were not smothered by crops at the early seedling stage but reached maturity, often developed more extensive root systems than the crops.

In conclusion, it may be said that annual weeds, which are usually of the greatest economic significance to agriculture, may be controlled by culitvation, and sometimes by chemicals (**9**). These measures, however, are expensive, and not very reliable. A thorough knowledge of the competitive efficiencies of various cereal and forage crops against different weeds, on the other hand, offers a more certain and cheaper

[To face p. 16

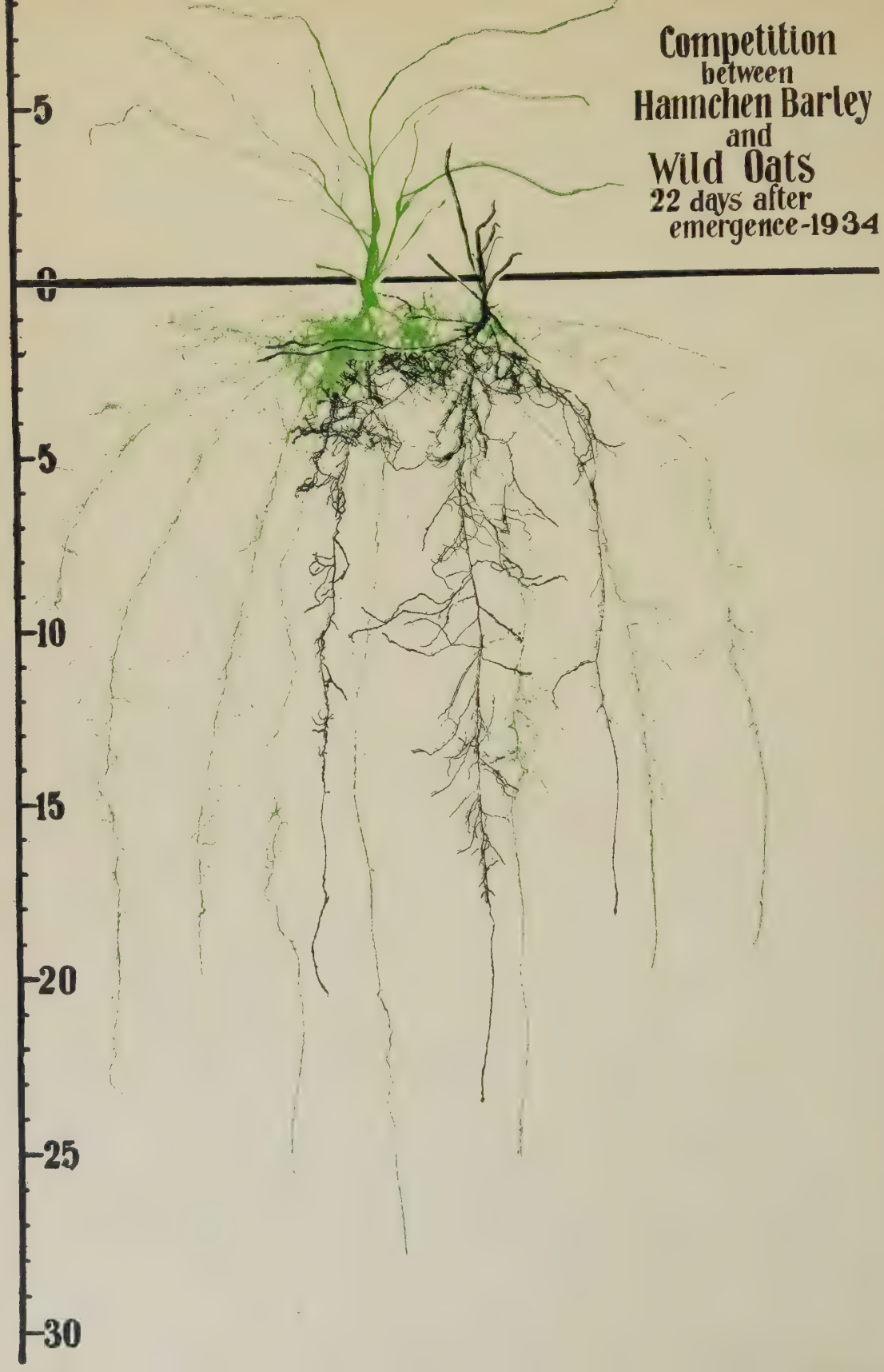
Competition between crop plants and weeds, twenty-two days after emergence.

Fig. 8.—Competition between Hannchen barley and wild oats.

Fig. 9.—Competition between Marquis wheat and wild oats.

Fig. 10.—Competition between Marquis wheat and wild mustard.

Prepared and drawn by T. K. Pavlychenko of the Field Husbandry Dept., University of Saskatchewan, from material grown in the Weed Nursery, Saskatoon, as a part of a co-operative Weed Research Project carried on jointly by the National Research Council and the University of Saskatchewan.


Competition
between
Hannchen Barley
and
Wild Oats
22 days after
emergence-1934
5
0
5
10
15
20
25
30

method for controlling these pests. The problem resolves itself mainly into questions regarding the particular crop to use, and time and rate of seeding in order to obtain satisfactory results when particular weeds are present. A degree of weed control is then obtained in proportion to the greater ability of the crop plants to utilize the existing environment. Their more rapid and uniform germination, and their ability to develop greater root systems at the early seedling stage enable them to occupy the soil more or less completely with their roots and the surface with their tops before the weeds become established.

(2) Nature of Root Systems of Various Plants

There is at present sufficient experimental evidence to indicate that crops suffer from weeds mainly because the latter utilize the limited supply of soil moisture at the expense of the former. This is particularly true in arid regions such as Western Canada and Central United States. The damage is primarily effected through activities of the root systems. For this reason a clear knowledge of the nature of these organs in different crop and weed plants is essential before any successful method of weed control can be safely recommended.

(a) Root systems of cereal crop plants

In the course of quantitative root studies at the University of Saskatchewan, it was definitely demonstrated that the root systems of different crop plants vary materially, not only in the amount of roots per plant, but also in their depth of penetration and distribution under the surface. Barley plants, for example, may produce root systems in size equal to or even smaller than those of wheat or oats, yet the root systems of barley will always exert a much greater competitive effect against weeds than those of similar size produced by wheat or oats. This is due to the fact that the barley plants spread the majority of their roots horizontally, and therefore rapidly occupy the inter-row spaces where weeds attempt to establish themselves soon after the crop has emerged. Available moisture in the top layers of soil is quickly depleted by the crop roots, and the weeds, which generally germinate a few days later, rarely develop normally. They persist for some time, but finally most perish. In the meantime the main roots of the crop penetrate deeply, and take full advantage of any moisture available in the lower soil strata.

Another important characteristic of the root system of barley is that it consists of from six to thirteen seminal roots against three or less in wild oats, three to four in cultivated oats, four to five in wheat, and five to six in spring rye. The seminal roots of spring and winter annual cereal crops were long considered as temporary organs dying off as soon as the crown roots are well developed. For plants in a dry climate at least, this conception is fundamentally wrong. Actually, they not only persist and function throughout the entire life of the plant, but in most years they are its main support from emergence to maturity. It is only in unusually wet years that the crown roots are developed to any appreciable extent to take an active part in supporting the top growth. With this in mind, it is easy to realize the importance for any species of one or several additional seminal roots per plant in its struggle for

survival with other plants. The data on this point secured from one hundred random plants of each crop excavated and analysed in different seasons are given in Table 8.

Table 8.

Average number of seminal roots per plant				
Wild oats	Banner oats	Marquis wheat	Prolific spring rye	Hannchen barley
3	3.5	4.4	5.6	6.3

This may be emphasized further by statistical data showing the ramifications of one such root. In 1934 it was determined that one root of wild oats 63 inches long, together with its branches of the first and second order, measured 256,675 linear inches, and possessed 146,176 absorbing root tips, which continued to penetrate new areas of soil throughout the growing season (**15**).

The root systems of spring rye, wheat and oats, unlike that of barley, have a more sloping penetration. Spring rye most closely resembles barley in this respect. Spring wheat takes an intermediate position, and oats the opposite extreme in this series. It is interesting to observe at this point that barley ranks as the most efficient competitor of weeds, followed successively by spring rye, wheat, and oats, irrespective of the basis upon which evaluation is made.

Figures 8, 9 and 10 show the root systems of crops and weeds as they actually grow and compete with one another under ordinary field conditions.

A graphical presentation of the quantitative relationships in percentages between the root systems of two important weeds and five standard cereal crops at different stages of their development is shown in Diagrams 1, 2 and 3.

(b) Root systems of forage crops

In a similar way, the nature, extent and distribution of the root systems of the leading forage crops in Western Canada serve to explain their ability to clear the land of volunteer vegetation. Crested wheat grass (*Agropyron cristatum*), for instance, produces a root system which frequently penetrates to a depth of seven or more feet (Fig. 11). Approximately 75 per cent of the total root material is located in the first foot of soil. The main roots spread widely and then penetrate deeply. The surface soil is thoroughly occupied by their extremely fine yet long-lived and strong branches of the first, second, third and frequently fourth orders. These utilize the available moisture in the ground so completely that annual weeds cannot become established in a solid stand of the grass, nor between rows of the grass spaced three feet apart. Brome grass (*Bromus inermis*) and particularly slender wheat grass (*Agropyron pauciflorum*) also possess great root systems. However, they spread much less, have a shallower penetration, are less resistant to processes of decomposition in the soil, and are therefore not able to control weeds as efficiently as crested wheat grass. This is particularly true of slender wheat grass. While crested wheat grass, when

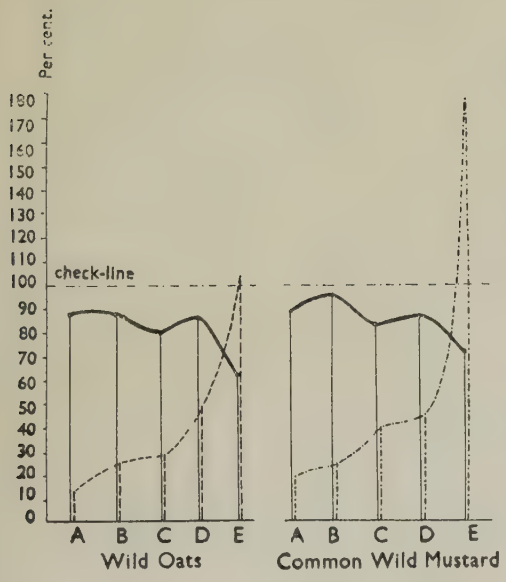


DIAGRAM 1.

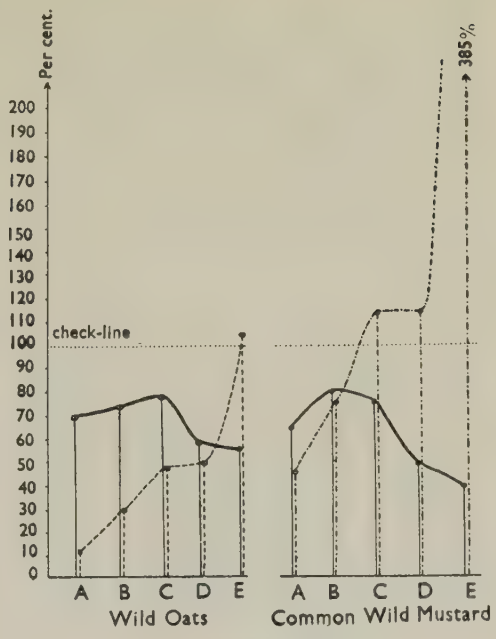


DIAGRAM 2.

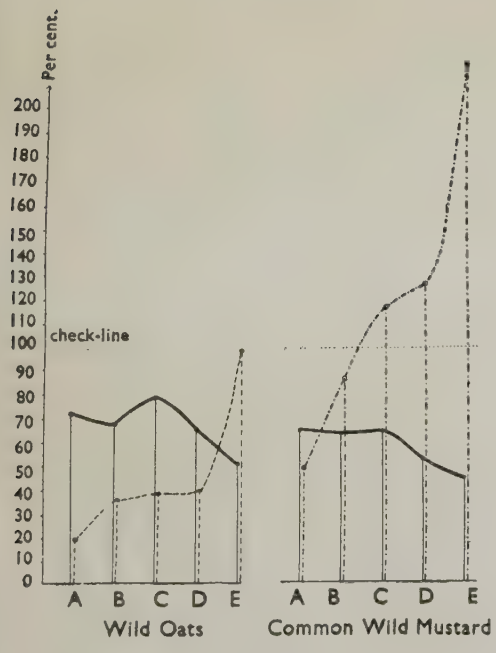


DIAGRAM 3.

DIAGRAMS 1, 2 and 3

Total lengths of the root systems of wild oats, wild mustard and five standard crops at 5, 22 and 40 days after emergence respectively.

A = Hannchen barley
B = Prolific spring rye
C = Marquis wheat
D = Banner oats
E = Bison flax

once established, will resist the invasion of annual weeds of all kinds almost indefinitely, and brome grass will hold its own for about six years after seeding; slender wheat grass is badly over-run by weeds in three years, irrespective of the density of its stand during the first two years. An examination of the entire root systems of these three grasses helps to explain their relative competitive efficiency (Table 9).

Table 9.—Linear dimensions of the root systems of single plants of three grass species. Plants spaced three feet apart in all directions

Species	Age of plants	Main roots	Length of branches of: 1st order	2nd order	3rd order	Total length	
	years	inches	inches	inches	inches	inches	miles
Agropyron cristatum	1	1,034	23,370	79,000	43,000	147,304	2.3
	2	14,100	1,784,000	18,450,000	Undetermined	20,248,100	319.5
	3	Undetermined		—	—	—	—
Bromus inermis	1	1,499	30,840	61,600	36,000	129,939	2.0
	2	11,900	1,497,000	7,832,000	Undetermined	9,340,900	147.4
	3	26,870	685,835	3,425,600	,,	4,138,305	65.2
Agropyron pauciflorum	1	2,031	31,274	73,700	47,000	154,005	2.4
	2	10,890	720,000	10,920,000	Undetermined	11,650,890	183.8
	3	8,396	405,000	216,000	,,	629,396	9.9

Additional data are given in Table 10 with respect to various grass species growing thickly in pure stands (sod). Grasses such as *Agropyron cristatum*, *A. smithii*,

Table 10.—Amount, length and soil-binding strength of root fibre produced by various native and cultivated grasses in a block of sod, 100 × 50 cm. in surface area and 10 cm. deep.

Species	Total weight of roots per block grm.	Total weight of roots per acre kg.	Length per block metres	Soil-binding equivalent* grm.
Agropyron cristatum	299.8	2,426.5	104,634.04	9,382
Agropyron pauciflorum	121.4	982.6	40,804.70	1,261
Bromus inermis	277.8	2,248.5	47,607.08	3,904
Poa pratensis	276.8	2,240.4	171,731.58	2,282
Sporobolus cryptandrus	214.0	1,731.1	30,722.36	1,352
Andropogon scoparius	187.8	1,520.0	37,725.68	1,623
Andropogon furcatus	345.0	2,792.4	21,169.74	8,402
Agropyron smithii	145.0	1,175.0	104,992.08	9,402
Bouteloua gracilis	123.0	995.5	20,287.24	2,114
Stipa spartea	154.0	1,245.6	18,234.89	5,123
Triticum vulgare	69.7	564.1	26,603.21	375

*Tensile strength of total root fibre per cubic cm. of soil (unpublished data).

Poa pratensis and *Bromus inermis* produce the highest quantities of root fibre, which enable them completely to control the available soil moisture. This excludes the possibility of other species becoming established in their habitats. Consequently their sods are generally free or almost free from weed plants. The tremendous length and strength of their root fibre at the same time binds the soil so thoroughly that neither wind nor water erosion is possible (**11**, **12**, **22**).

The remaining species behave likewise, but to a much lesser degree, and usually in proportion to the amount, length and strength of the root fibre produced per cubic volume of their sods.

(c) Root systems of perennial weeds

Weeds such as perennial sow thistle (*Sonchus arvensis*), Canada thistle (*Cirsium arvense*), field bindweed (*Convolvulus arvensis*), poverty weed (*Iva axillaris*), leafy spurge (*Euphorbia esula*), etc. constitute a separate group with respect to the nature of their root systems. Their perennial roots serve not only as organs for the absorption of soil moisture and nutrients, but also for the storage of food reserves and as a means of vegetative propagation. For these reasons, their eradication is not possible without complete destruction of their subterranean parts (**1**). In this connexion, a knowledge of the morphological features, anatomical structure, and mode of penetration and distribution of their root systems is highly desirable. A study of these features at Saskatoon which has furnished information of considerable practical interest may be summarized as follows :

1. Perennial sow thistle distributes its roots mostly within the first six inches below the surface. The vertical roots penetrate freely to a depth of six feet. Both the horizontal and vertical roots may be from 1 to 7 mm. in diameter. They are very succulent and covered with a thin and weak bark ; these facts constitute a basis for successful eradication in one season. By applying a shallow, but thorough surface tillage and preventing top shoots appearing above the surface for a period from ten to twelve weeks, the food reserves stored in the roots are depleted, and the roots themselves are weakened. In this condition the thin epidermis affords the roots little protection against decomposition and they decay very rapidly.

2. Quack grass (*Agropyron repens*) is another principal perennial weed in Western Canada. Its persistency is due to the presence of long stolons with numerous vegetative buds and a multitude of fibrous roots. Fortunately this weed may also be eradicated completely in one season by shallow surface cultivation, which totally prohibits top growth for fourteen to sixteen weeks.

3. Canada thistle has two types of horizontal runners, and also deep vertical roots arising either directly from the seed or from the runners. Horizontal runners of the first type keep close to the surface and produce numerous top shoots, but never terminate with vertical roots ; they serve to propagate the species in radial directions. The horizontal runners of the second type usually originate from the tap root of the parent plant at a depth below 12 inches, travel horizontally only short distances, then turn downward and give rise to vertical roots. These runners serve the purpose of supporting and propagating the species in dry years, when the superficial runners

become dormant or die. The roots of Canada thistle are protected with a much stronger bark than those of perennial sow thistle. Being impregnated with corky substances, they resist decomposition for a considerable time.

4. The roots of poverty weed, field bindweed, hoary cress, and leafy spurge possess an extremely thick corky layer in their bark, abundant food reserves, and penetrate to a depth of 12 to 20 feet below the surface. For these reasons they may resist successfully a complete inhibition of their top growth for a period of one season without noticeable loss of vigour. In the second consecutive year of this treatment, they suffer noticeably, but often preserve some of their vitality even after three years. In small patches, these and other perennial weeds may be completely eradicated in one season by chemical treatment. A typical root system of leafy spurge is shown in figure 12.

(3) Optimum Depth of Germination of Weed and Crop Seeds in Relation to Weed Control

For every species there is a specific depth from which seeds germinate most readily under field conditions. In shallower positions they germinate very unevenly. At greater depth they may refuse to germinate at all unless brought back to the surface by cultivation. This fact has a very important practical significance under the arid climate of Western Canada. If weed seeds are placed at the optimum depth for germination, while crop seeds are buried too deep, a weedy harvest will result, even on land where weed infestation is comparatively light. On the other hand, when crop seeds are placed at an optimum depth, a clean crop may be expected even on weedy land, because cereal crops under such conditions germinate quickly and produce dense uniform stands. Weeds, which as a rule develop slowly at the early seedling stage, are at first out-grown, then overtopped, and finally smothered by the crop plants. In dry districts, small-seeded weeds are particularly exacting with respect to the optimum depth of germination. Seeds of Russian thistle (*Salsola kali*), for instance, germinate readily only if placed directly on the ground, or not deeper than 0.5 in. below the surface. Wild mustard (*Sinapis arvensis*), stinkweed (*Thlaspi arvense*), lamb's quarters (*Chenopodium album*), and many others germinate most readily at a depth of from 0.5 to 1 in. below the surface. If buried much deeper, they remain dormant for several seasons. Deep ploughing therefore tends to increase the weed-seed population in the ground. The final result is that, in time, the cultivated layer of soil becomes permeated with weed seeds to such an extent that sufficient are located at the optimum depth for germination irrespective of the method of tillage used for weed control.

This marks the time when the weed problem becomes acute. The situation is almost hopeless if the optimum depth of germination of the weeds in question is disregarded and deep cultivation continues. Shallow surface tillage practised for several seasons, however, destroys most of the viable seeds at the surface, while those located below the depth of cultivation gradually decay and lose their vitality.

The depth from which seeds produce the highest percentage of germination in the shortest time is considered to be the optimum. The depths determined for common weeds and crops were as follows (Table 11).

Fig. 11.

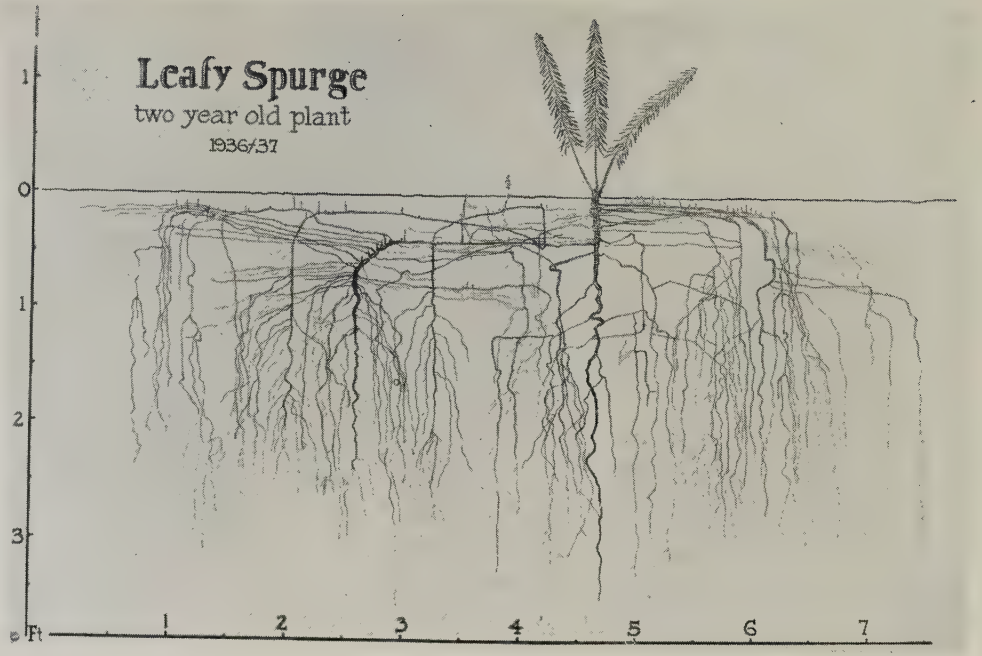


Fig. 12.

Fig. 11.—Root system of two-year-old single plant of crested wheat grass (*Agropyron cristatum*).

Fig. 12.—Root system of leafy spurge (*Euphorbia esula*).

To face p. 22

Table 11.

Species	Optimum depths inches	Number of days from seeding to emergence	Percentage germination in five days after the first emergence
Avena fatua	2.5	10	43.5
Lolium temulentum	2.5	10	47.3
Saponaria vaccaria	2	7	41.1
Sinapis arvensis	1	9.5	37.0
Thlaspi arvense	1	6	34.2
Polygonum convolvulus	0.5	20.6	26.6
Salsola pestifer	0.5	10.8	37.8
Chenopodium album	1	11.6	31.6
Axyris amarantoides	1	9.3	24.0
Marquis wheat	2.5	5	86
Banner oats	2.5	5	81
Prolific spring rye	2	3	96
Hannchen barley	2	4	89
Bison flax	1	6	57

The effectiveness of shallow surface tillage in placing the weed seeds at their optimum depth of germination for weed control was given a thorough practical test. The field used for plot work received, in addition to natural infestation, an enormous annual quantity of weed seeds in connexion with weed experiments. While the regular practice of ploughing the land was used, the infestation continued to increase rapidly, and extensive hand pulling was necessary to obtain check plots free of weeds. In 1932 the ploughing was abandoned, and shallow surface tillage used exclusively. Since that time no hand pulling of weeds has been necessary in the check plots.

(4) Eradication of Perennial Weeds

The most serious perennial weeds in Western Canada propagate both by seed and by subterranean roots. The young plants originating from the seeds possess no perennial root stalks for several weeks, remain small, and, unlike the annual weeds, seldom produce seed in the first year of growth. For this reason they are easily destroyed by cultivation during the early stages of growth. However, as soon as these seedlings develop perennial roots their destruction becomes extremely difficult. Any small section of a perennial root is capable of re-growth, and of establishing a new patch. Therefore, *a hundred per cent kill or complete eradication of both top growth and perennial roots must be the ultimate goal in every case* (**10**). This may be easily

obtained in small patches by chemical treatments. Sodium chlorate (**2, 6**) and arsenic pentoxide (**7**) of the commercial mixtures, or these compounds with other fillers proved very effective, irrespective of the weed species treated. The treatment must be thorough, and heavy enough to render the soil sterile for at least two or three years. It must be clearly understood that the killing efficiency of a chemical depends entirely upon its ability to sterilize the top soil for a long time, and not upon its ability to circulate through the plant's system, a claim that is sometimes made by commercial agents selling chemical weedkillers. The explanation lies in the fact that subterranean roots, unharmed by the chemical, continue to send numerous new shoots to the surface, and these are destroyed while attempting to protrude through the sterile layer of the top soil (**7**). In time, the food reserves in the *roots* are exhausted, and they die of suffocation and starvation without coming into contact with the chemical. This is why there are so many good chemicals for controlling annual weeds, where prolonged sterility of the soil is not essential, while only a few remedies are known for perennial weeds.

The eradication of perennial weeds by chemicals on a large scale, however, is impracticable, as the cost is prohibitive. Fortunately eradication in many cases can be accomplished satisfactorily by cultural methods. A shallow, yet thorough, black summer-fallow proved to be fully effective in the case of perennial sow thistle, quack grass and Canada thistle. The emphasis must be placed on "shallow" cultivation, as deep cultivation does not add materially to the effectiveness of the treatment, and is slow and expensive. As in the case of chemicals, the extent of direct mechanical injury to the plants is not important, but it is necessary to prevent completely all shoots from appearing above the surface for a definite length of time. By this method, roots of perennial sow thistle are completely killed, irrespective of their depth of penetration, in 10 to 12 weeks (**16**). Quack grass was destroyed in 12 to 14 weeks (**17**). For these two weeds, in Western Canada, the treatment may commence at any time between the beginning of June and the end of July. Canada thistle also may be successfully eradicated by this method in one season. However, its perennial roots are stronger, contain more reserves, and are better protected from decay. For these reasons, they resist the treatment more vigorously. To be effective the work must commence not earlier than at the blooming stage, when root reserves are most exhausted, and continue until the soil is frozen (**18**).

Regarding eradication of poverty weed, field bindweed, hoary cress and leafy spurge on a large scale, a cheap and quick method remains to be discovered.

(5) Practical Recommendations for Weed Control under Dry Farming Conditions

1. Use clean seed.
2. Include barley in grain farming rotations for controlling annual weeds.
3. Use shallow surface tillage instead of deep ploughing wherever practicable to avoid burial of weed seeds beyond their optimum depth for germination.
4. Sow grain crops at their optimum depth for germination, to produce a thick and uniform stand soon after seeding.
5. On weedy land, increase rate of seeding by 50 or 75 per cent as compared with the amount used on clean land.

6. In the cropping year apply shallow surface tillage immediately after harvest to promote maximum germination of the weed seeds by placing them at the optimum depth.
7. During the summer-fallow year, encourage weed growth, and destroy plants in the seedling stage by surface tillage (green summer-fallow).
8. From time to time, sow weedy fields to coarse grains, and cut for green feed before the weeds mature and scatter their seeds.
9. Where weed infestation is serious and cannot be controlled by extensive cultivation because of severe soil drifting, seed the land to perennial grasses such as brome grass, crested wheat grass, or these mixed with alfalfa, and leave the field in sod for three or four years.
10. Eradicate perennials in small patches by sodium chlorate, or commercial mixtures of this chemical.
11. Use shallow black summer-fallow for eradication of perennial sow thistle, Canada thistle and quack grass.
12. Apply deeper cultivation for keeping in check such perennial weeds as poverty weed, hoary cress, leafy spurge, Russian knap-weed and field bindweed, which cannot be eradicated in one season by the shallow black summer-fallow method.

Summary

The following summarizes the organization and nature of the work on weeds in Canada :

1. Until 1929 the work was carried on by Dominion Experimental Stations, and by the Provincial Departments of Agriculture throughout Canada.
2. In 1929 a Provincial Conference in Regina emphasized the need for special research on the problem of weed control, and as a result funds were made available for a number of provincial projects.
3. In the same year at Edmonton, Alberta, the National Research Council of Canada undertook the task of organizing an Associate Committee on Weed Control to co-ordinate the work throughout the Dominion.
4. In 1935, this Committee was re-organized again in order to effect the closest possible co-operation in weed research between the Dominion Department of Agriculture, and the National Research Council of Canada.
5. Under this Committee the work was directed along the following principal lines :
   (a) Survey of the distribution of the main annual and perennial weeds in Western Canada.
   (b) Control of annual and perennial weeds by chemicals and cultural methods.
   (c) Biological study of annual and perennial weeds and crop plants, with particular reference to their competitive efficiency and ability to resist injury from cultivation and chemical treatments.
6. Various sections of this article deal in more or less detail with (1) the nature of plant competition, (2) studies of root systems, (3) optimum depth of germination, (4) eradication of perennial weeds, and (5) recommendations for weed control in Canada.

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R. H. F. Manske **Canada**

CHEMICAL ANALYSES AS AN AID TO CLASSIFICATION OF POISONOUS PLANTS

It has long been known that the chemical constituents of closely related species of plants are not necessarily the same. Many examples might be given, but the following will serve to illustrate the point. In the genus *Cinchona*, it has been found that the alkaloids, and particularly the minor bases, vary greatly from species to species, although cinchonine and quinine are nearly always present. In the genus *Strychnos*, it is not at all uncommon to find a species which does not elaborate strychnine. Recent work on *Lupinus* and other genera of the same family has shown that each species elaborates a specific group of alkaloids.

It is, therefore, a reasonable corollary that two plants which may be distinguishable with difficulty on taxonomic evidence may be distinguishable on the basis of a chemical examination. It is not suggested that it will always be found possible to set up criteria of specificity based upon chemical evidence. In the case of plants which contain alkaloids, however, it is believed that such criteria can be found. Some thirty species of *Senecio* have been examined for alkaloids and only in five of them has the alkaloid, senecionine, been found. It is interesting to note, however, that in these five cases the species are easily distinguishable taxonomically. The writer has recently had occasion to examine *S. spartioides*, *S. longilobus*, and *S. ridellii*, three species which have been relegated to a prior species, namely, *S. douglasii* (Index Kewensis). In view of the fact, however, that the alkaloids which each elaborates differ from those of the others, the reduction to *S. douglasii* is not justifiable; in fact, several botanists who were consulted preferred to retain the separate names. There are some 1,600 species of *Senecio* and in many cases it is a matter of considerable difficulty to define the limits of a species. In such cases the isolation and identification of the alkaloid or alkaloids are almost certain to give a decisive answer.

It is, therefore, suggested that the chemical examination of all plants known to contain or suspected of containing alkaloids be pursued with some vigour. This is especially true in the following genera :—

Senecio	*Lupinus*
Corydalis	*Lobelia*
Fumaria	*Delphinium*
Dicentra	*Aconitum*

and those in which specific differences may be slight. The writer will be pleased to communicate further with those interested in the problems here stated, and in many cases is prepared to undertake the chemical examination if the material is available.

L. W. Kephart U.S.A.

THE FARM WEED PROBLEM IN AMERICA

The Weed Situation

To a traveller from Europe, accustomed to the neat hedgerows and hand-tended fields of Britain and the Continent, the United States is likely to seem a weedy country. In a three-thousand-mile traverse of North America the visitor's impressions are apt to be influenced quite unfavorably by the prevalence of weedy field-borders, unkempt pastures, wide, overgrown fence rows, and unsightly roadsides. His first conclusion may well be that Americans are untidy, albeit very productive, husbandmen.

In extenuation of this seemingly slack culture, it must be remembered that American agriculture, while past the pioneer stage, is still an extensive type of enterprise. The nearly 7,000,000 farms in the United States contain, on the average, 155 acres allocated 60 acres to crop land, 76 acres to pasture, 12 acres to woodland, and 7 acres to farmstead and waste land. This average farm, which may vary in locality from sub-arctic to sub-tropic and in product from spring wheat to sugarcane, is operated by the equivalent of approximately 1.5 man-years of labor. In other words, each American farmer is responsible, on the average, for all the crops, livestock and livestock products produced on 100 acres. This is a high ratio of land to labor, made possible only through a high degree of mechanization involving the use of the most efficient farm machinery, operated by a mechanically-minded people. In such a system of agriculture, hand labor is, of necessity, subordinated. Only the types of weed control that contribute to the farm income are regarded as essential. Consequently, fence rows are likely to be mowed but once a year if at all, pastures are left pretty much to themselves, and roadsides are attended to only when and if convenient.

Probably neglect of weeds in America is somewhat more apparent than real. True, the losses attributable to weeds if taken literally approach astronomical figures, in one widely quoted estimate exceeding three billion dollars a year. Unquestionably, some of these losses are due to carelessness and should be avoided. Nevertheless, and disregarding aesthetic values, there is room for argument as to the kinds of losses that are economically important. The conspicuous weeds in America are chiefly summer annuals of a kind not well-known in Europe although, curiously, most of European origin. Practically every field of small grain (cereal) in the vast area east of the Rocky Mountains grows up after harvest in a solid mass of ragweed (*Ambrosia elatior* L.), Russian thistle (*Salsola pestifer* Nelson), marsh elder (*Iva xanthifolia* Nutt.), sunflower (*Helianthus* spp.), (an American genus), foxtail (*Chaetochloa* spp.), or other annual weeds. Corn (maize) and cotton fields are likely to have, in late summer, an under-storey of foxtail, smartweed (*Polygonum* spp.), or crabgrass

(*Digitaria sanguinalis* (L.) Scop.). These weeds are unsightly, cause suffering from hay fever, interfere with new seedings of grass and clover, or are otherwise obviously objectionable. Yet farmers universally look upon their presence with tolerance if not with complacence.

The point appears to be that farmers in America have discovered, through years of trial and error, a point of diminishing returns beyond which it does not pay to devote labor to the eradication of incidental weeds. This is conspicuously true in the case of " inter-tilled " crops like corn, cotton, potatoes and beans. Both practical experience and scientific experiment indicate the need of suppressing weeds in such crops while the crops are young. Thus, a scene characteristic of America in early summer is the horse- or motor-drawn " cultivator " going slowly down long rows of corn or cotton, sweeping the ground clear of weed seedlings between the rows. This operation, repeated every week or ten days, is one of the heaviest items of expense in growing inter-tilled crops ; consequently the crop is " laid by", i.e., cultivation ceases, as soon as the crop is large enough to take care of itself. This permits a certain number of weeds to survive and produce seeds, but it is not considered worth while to attempt to destroy them.

Formerly this stirring of the soil between the rows was believed to be valuable because of moisture conservation, soil aeration and similar considerations. Now it is known that the principal value of inter-tillage is to destroy weeds, other values being incidental if they exist at all. In recent years the practice of inter-tillage has been subject to severe criticism on the score of contributing to soil erosion. Contour planting has been suggested as a remedy, and this doubtless will be adopted to some extent. Nevertheless, it is evident that the time is approaching when the control of weeds must be effected by methods which reduce the hazards of erosion now so considerable in inter-tilled crops. The discovery of such methods is probably the largest single problem facing the weed investigator in America to-day.

In other respects annual weeds in America, while conspicuous and costly, are not the most difficult problem in weed control. For the most part farmers can be depended upon of their own accord to hold them within reasonable economic, if not aesthetic, limits.

The most urgent weed problem in the United States at the moment is that of the persistent, aggressive, destructive, chiefly perennial species for which there is no adequate control. During the past fifteen or twenty years these " noxious " weeds, so-called, have become a real and growing menace to many branches of American agriculture. In the States west of the Mississippi River, about 6,000,000 acres of excellent farm land are so thoroughly occupied by noxious weeds that continued crop production is seriously menaced. In many areas whole fields and in some districts entire farms and even townships have been so badly damaged by these weeds that the situation has become one of widespread public concern.

Fifteen years ago the area covered by noxious weeds did not greatly exceed 1,000,000 acres, rather generally distributed and under fairly good control. In 1930 began an unusual series of dry years. Concurrently, economic depression settled on the nation. The first provided conditions highly favorable for seed

production, the second brought a marked increase in farm tenancy and a general reduction in farm care. The combination gave a perfect opportunity for the weeds to spread. Possibly these circumstances will not be present in such marked degree in years to come. The indications are, however, that the present situation will not greatly improve and that noxious weeds will continue to increase, unless vigorous measures are taken to combat them.

About twenty perennial and five annual weeds comprise the list of the more important noxious species. Most widely disseminated and most rapidly increasing is wild morning-glory or bindweed (*Convolvulus arvensis* L.). More than one and one-half million acres are infested with bindweed, chiefly west of the Mississippi River, but occasionally eastward. It occurs on any non-acid soil under humid, dry-farming or irrigated conditions. On deep loess soil along the Missouri River, the roots of bindweed have been found to a depth of thirty feet.

Several other weeds are troublesome in only slightly less degree. In the South and Southwest, Johnson grass (*Sorghum halepense* (L.) Pers.) has been a problem for fifty years, as have nutgrass (*Cyperus rotundus* L.) and Bermuda grass (*Cynodon dactylon* (L.) Pers.). In the North and West, quackgrass (*Agropyron repens* (L.) Beauv.) and Canada thistle (*Cirsium arvense* (L.) Scop.) have long been well established, while whitetop (*Lepidium draba* L. and related species), horse nettle (*Solanum carolinense* L. and *S. elaeagnifolium* Cav.), Russian knapweed (*Centaurea repens* L.) and leafy spurge (*Euphorbia esula* L.) cause increasing concern. Dodder (*Cuscuta* spp.) is ubiquitous. Of more local occurrence are wild garlic (*Allium vineale* L.), St. John's wort or Klamath weed (*Hypericum perforatum* L.), Austrian field cress (*Roripa austriaca* Bess.), perennial sow thistle (*Sonchus arvensis* L.), blue lettuce (*Lactuca pulchella* (Pursh.) DC.; poverty weed (*Iva axillaris* Pursh.), puncture vine (*Tribulus terrestris* L.), bitterweed (*Helenium tenuifolium* Nutt.), and several species of wild mustard (family Cruciferae).

American Weed and Seed Laws

There is in the United States no Federal or National law covering weed control except in so far as this may be accomplished through the operations of the new Federal Seed Act. In the American tradition regulatory laws of purely local effect are a function of the State rather than the Federal authorities, and weed control has been considered to be in that category. In consequence, nearly every State has had on its statute books for many years laws empowering county and municipal officials* to compel property owners to destroy the weeds growing on their land. These laws are simple in structure and require in general only that the county officials notify landowners to cut weeds before a given date, failing which the county may do this and assess the costs against the property. In practice, these State weed laws have not been very effective, probably because (1) enforcement of the law was discretionary rather than obligatory upon the part of the county supervisors; (2) the officials were too busy with other duties to attend to weed control; and (3) the county

*In the United States the County is the chief sub-division of the State, and is governed by a Board of County Supervisors or comparable body having specified local authority.

supervisors are elected representatives and naturally hesitate to antagonize their constituents unnecessarily.

Realizing the ineffectiveness of their weed laws, thirteen States* since 1937 have adopted new or revised laws affecting weed control. In some cases, these are merely amendments to the seed laws. In others, specific weed laws have been adopted. Several different and very interesting plans have been devised in the attempt to make these laws workable. Typical are those of Iowa, Nebraska, and Kansas.

The Iowa law is based upon the old type weed law, but gives more authority and responsibility to the County Supervisors. Salient features are:

(1) Eight plants are designated "primary noxious" and nine "secondary noxious" weeds.†

(2) The State Secretary of Agriculture is appointed State Weed Commissioner with power (a) to appoint a State Botanist who shall suggest suitable weed control measures; (b) upon recommendation of the State Botanist, temporarily to declare noxious any weed which possesses the characteristics of a serious pest; and (c) to aid the County Supervisors in the interpretation and enforcement of the State weed law.

(3) The Board of Supervisors *shall* appoint either a County Weed Commissioner or one Township Weed Commissioner for each township in the county.

(4) The County or Township Weed Commissioner is the one who enforces the law. He has the power to enter if necessary upon private land in order to destroy noxious weeds and is responsible for the control of weeds on county roads. He is expected to obtain the co-operation of farmers in working out cropping programs that will, over a period of years, destroy large infestations of weeds, since it is recognized that chemical treatment is too expensive for large areas. It appears to be the intent of the law that the weed commissioners shall depend largely upon friendly persuasion, but shall have legal authority when necessary.

Thus, by making performance of the law obligatory rather than permissive upon State and County officials, by specifying a responsible officer and by describing his duties in detail, it is believed that the weaknesses of the old type of law have been overcome.

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*Iowa, Illinois, Wisconsin, Minnesota, Nebraska, Kansas, Wyoming, Montana, Utah, Idaho, Washington, Oregon, and California.

†Primary noxious weeds: Quackgrass (*Agropyron repens* (L). Beauv.), perennial sowthistle (*Sonchus arvensis* L.), Canada thistle (*Cirsium arvense* (L.) Scop.), European bindweed (*Convolvulus arvensis* L.), horse nettle (*Solanum carolinense* L.), leafy spurge (*Euphorbia esula* L.), perennial peppergrass (*Lepidium draba* L.), and Russian knapweed (*Centaurea repens* L.).

Secondary noxious weeds: Butter-print (*Abutilon theophrasti* Medic.), cocklebur (*Xanthium commune* Britton), wild mustard (*Brassica arvensis* (L.) Ktze.), wild carrot (*Daucus carota* L.), buckhorn (*Plantago lanceolata* L.), sheep sorrel (*Rumex acetosella* L.), sour dock (*Rumex crispus* L.), smooth dock (*Rumex altissimus* Wood), and puncture vine (*Tribulus terrestris* L.).

A second type of new weed law, exemplified by that of Nebraska, has quite a different basis. In this law the essential feature is the voluntary formation of "noxious weed eradication districts". In this plan, 51 per cent of all resident landowners, or persons owning 60 per cent of the land in any rural area not less than 1 square mile in extent, may form a noxious weed eradication district by filing with the County Clerk of the county a petition stating the name of the proposed district, describing all of the lands to be enclosed and declaring that the owners of the land will pay any tax that may be necessary to cover the expense of operation of the district. The County Clerk shall then deliver a copy of the petition to the Director of the State Department of Agriculture, who shall cause a survey to be made of the district and upon approval by a State Weed Advisory Committee file a report with the County Clerk. After a suitable hearing of all persons interested and unless good reason is shown to the contrary, the Board of County Supervisors shall order the formation of the district. Thereupon the County Clerk shall call a meeting of all landowners in the district at which three to five district supervisors shall be elected. Under the advice of the Director of the State Department of Agriculture these supervisors shall then have charge of the eradication of noxious weeds within the district. Detailed plans for the organization and financing of the district are provided by law.

This type of weed legislation is a new departure, although patterned after other kinds of pest control legislation that have proved satisfactory. The essential fact that the impetus for action comes from the farmers themselves rather than from officials is believed to give better assurance of performance.

A third type of State weed control is embodied in the law of Kansas. Discussion of this will be found under Weed Control Programs.

In the matter of seed laws there are both Federal and State statutes. In 1940 there will come into effect a new Federal Seed Act superseding the Federal Seed Act of 1912. The new Act not only enlarges Federal control over importations of agricultural and vegetable seeds, but will for the first time give the United States Government supervision over the shipment of seeds between States. This is a most important provision. Of the forty-eight States in the Union, all but Georgia and Florida have seed laws under which the sale of seeds within the State is subject to supervision. The weakness of this system has been lack of adequate control over the shipment of seeds between States, for seeds unfit for sale in one State could be "dumped" in another State with little risk of serious penalty. Under the new Federal law, all seeds shipped in interstate commerce must be properly labeled and in "noxious" weed content are subject to the requirements of the State into which the seed is shipped, under penalty of Federal prosecution. This is no hardship to those who have been shipping seed in interstate commerce completely labeled in compliance with State seed laws. Only those shippers of seed in interstate commerce who have not completely labeled such seed will find it necessary to alter their practices materially in order to comply with the new law. Particularly affected will be those who move seed directly to consumers by motor truck or through the mail. This has been a growing practice of recent years and has unquestionably been the cause of the dissemination of much seed of very poor quality.

Before performance of the interstate provisions of the Federal Seed Act can become fully effective, it may be necessary to bring about more uniformity in the State seed laws. For example, all State seed laws except that of New Hampshire specify from five to forty weed seeds which are, to a greater or less degree, prescribed. Indicating the diversity of opinion among legislators as to the kinds of plants which are noxious weeds, no less than 160 species or genera are listed in these laws. Naturally, seed dealers doing a nation-wide business find much difficulty in meeting forty-six different requirements, and a concerted effort is now being made to simplify these statutes.

Under the import provisions of the new Federal Seed Act the following weeds are declared to be noxious and commercial seeds containing more than a very small percentage of seeds of these weeds will be refused entry into the United States :

Lepidium draba L.
Lepidium repens (Schrenk.) Boiss.
Hymenophysa pubescens C. A., Mey.
Cirsium arvense (L.) Scop.
Cuscuta spp.
Agropyron repens (L.) Beauv.
Sorghum halepense (L.) Pers.
Convolvulus arvensis L.
Centaurea picris Pall.
Sonchus arvensis L.
Euphorbia esula L.

In addition, no seed may be imported if it contains more than 2 per cent by weight of any of a long list of weed seeds which are prescribed by the Secretary of Agriculture.

Weed Research Programs

Research on methods of controlling weeds has been in progress in a rather desultory manner in the United States for more than fifty years. Each State in the Union has a State Agricultural Experiment Station affiliated with its Agricultural College and its Agricultural Extension Service. At one or another of these stations from time to time, the Botanist or occasionally the Agronomist has pursued research on weed control or weed taxonomy. Only rarely, however, have first-class facilities for research in this line been available, with the result that the number of publications on weeds has been limited. Similarly, in the Federal Department of Agriculture projects on weed control research have been of brief duration and, although a certain number of papers of both technical and popular nature have been published, the effort has been disjointed.

In 1935, as a result of the increasingly serious weed situation in the western States, the United States Congress provided an appropriation to the Bureau of Plant Industry for " the investigation of methods of controlling bindweed and other noxious weeds ". A second appropriation to the Bureau of Chemistry and Soils provided for the " investigation of the cost and methods of producing herbicides, especially sodium chlorate ". Acting on this authority, the Bureau of Plant Industry organized a series of weed research stations in co-operation with the State Agricultural Experiment Stations in Minnesota, Iowa, Nebraska, Kansas, Idaho, Washington, California and Nevada. The first six named are primarily for research on the control of bindweed. The California project involves the technical aspects of chemical weed-killers ; the Nevada program is concerned with whitetop. In the bindweed

work, experimental stations were established on carefully selected farms where bindweed had thoroughly occupied the land. A series of ten uniform experiments was undertaken simultaneously at all stations. Each station also undertook individual experiments of other kinds.

The ten uniform experiments were designed to bring to light the fundamental principles governing the control of perennial weeds, and are concerned particularly with the effect of various tillage and cropping practices on the storage and use of food reserves in the roots. The nature of the experiments is indicated in their titles :

1. The seasonal trend of root reserves.
2. The trend of root reserves after cultivation.*
3. Time of beginning cultivation.
4. Frequency of cultivation.
5. Autumn-planted competitive crops.
6. Biennial and perennial competitive crops.
7. Summer-planted competitive crops.
8. Time of applying chlorates.
9. Methods of applying dry chlorates.
10. Rate of applying chlorates.

In the course of these experiments thousands of samples of roots have been dug from carefully measured areas of soil at various depths and at stated intervals. After separation from the soil the roots are dried, taken to the laboratories, and examined for their chemical content. At first a complete " feed analysis " was obtained, since it was not known whether any of the constituents except the carbohydrate fractions had a measurable part in the rejuvenation activities of the plant. Statistical examination of the data thus far obtained indicates, however, that for all practical purposes the only component that need be considered in determining the course of root reserves in normal or disturbed bindweed is the carbohydrate fraction. Attempts are now being made to develop a quick means of measuring the carbohydrate content, since such a method would greatly reduce the cost of analysing root samples or make possible the examination of a larger number.

The investigations of bindweed under the new Federal-State co-operation constitute the first large-scale attempt in the United States to co-ordinate inquiry into the fundamentals of weed behaviour and control.

One important fact has already been discovered through these studies of root reserves. Formerly the standard recommendation for killing a perennial weed was to keep it cut off at the ground level and never permit it to form any leaves. This meant, in the case of bindweed, cultivating every seven or eight days for at least two years. Such a schedule was almost impossible for a farmer to maintain. Through study of the root reserves and co-ordinated tillage trials, it has been found that the plant continues to draw on its stored food several days after the top emerges,

*" Cultivation " in this case means tillage with an implement known as the duckfoot or blade cultivator. This consists of a long blade or a series of V-shaped blades so designed that when drawn through the ground at a depth of 3 or 4 inches all plants in a swath 6 to 10 feet wide are severed.

and that the plant can be killed most effectively by allowing it to make four or five inches of top-growth between cultivations. This means, in practice, cultivating every fourteen to twenty days instead of every seven or eight days, a vast difference in practicability. Already wide-scale programs of control by tillage have been started as a result of these experiments.

The investigations of the State Experiment Stations have paved the way in this respect. Notable examples have been the study of the physiological action of herbicides at the University of California, the study of tillage practices at the Experiment Stations in Utah, Colorado, Kansas, and Nebraska, and experiments with herbicides in New York, Ohio, Iowa, Kansas and Idaho. An important event in American weed research was the discovery by Latshaw and Zahnley at the Kansas Agricultural Experiment Station in 1927 of the efficacy of sodium chlorate as a weed killer on bindweed. Many of the projects on weed control begun since that time owe their inspiration to this event.

The attitude towards weed control research in the United States may be said to have undergone a considerable metamorphosis during the past six or seven years. Instead of being regarded as somewhat of a nuisance, weed control investigations have achieved major status and have become part of the basic research program at a dozen or more State Experiment Stations. Naturally, the attitude of each Station toward weed control research depends entirely upon the seriousness of the weed situation in that State and the present activity of each State is a close reflection of the prevalence of noxious weeds in that area. Possibly the greatest need at the moment is for research in the South on Johnson grass, nutgrass, bitterweed, and other weeds of that region. Other needs of particular insistence are for the investigation of pasture and range weeds, aquatic weeds, weeds under irrigated farming, weeds affecting human and animal health, weeds deleterious to wool, milk and other products, and numerous phases of the problem of chemical weed-killers.

Weed Control Programs

As is the case with weed laws, there is in the United States no centralized or Federal agency responsible for weed control. The Works Progress Administration, the agency in charge of Federal unemployment relief, has accepted weed control as a suitable activity for unemployed labor and has sponsored a number of weed projects in areas where weeds are particularly bad. No other Federal agency has sponsored weed control except in a limited way.

The largest WPA project, and a very successful one, has been in Idaho. For several years, the WPA has there furnished labor for the control of weeds on both public and private land in a co-operative plan whereby the State, the Counties, and the individual landowners provide motive power, chemicals, and implements. The program is supervised by the State Extension Agronomist, an employee of the State Agricultural Extension Service. Work is performed by crews of three to twenty men operating under WPA foremen, following a strictly outlined itinerary and using methods specified in detail by the State authorities. The program was well conceived and has been well executed. Weeds on thousands of acres have already been

destroyed and it is believed that most or all infestations in the State will be brought under control before the program is completed. During the first two or three years the plan was based upon control with chemicals. Millions of pounds of sodium chlorate were distributed both as a spray and as the dry salt directly to the soil. Extensive use has also been made of carbon disulfide. This was an unexpected development since this pungent liquid, while known to be injurious to plant tissues, was not believed to be practicable for use in the field. In the hands of Idaho workers, carbon disulfide has been developed into a very satisfactory herbicide. By means of a specially devised implement, dosages of 2 ounces of carbon disulfide are injected into holes in the soil one inch in diameter, 6 to 8 inches deep, and 18 inches apart each way. The holes are immediately closed, whereupon the fumes permeate the soil and kill all roots to a depth of 18 inches or more. A considerable technique is involved, but with crews of trained laborers the chemical is not difficult to handle. Carbon disulfide cannot be used on impermeable, plastic soils, on coarse sands or gravels, or on soils having a high water table. Among farmers on high-priced irrigated land in southern Idaho, " carbon " is more popular than " chlorate ". The cost of using carbon disulfide is between $150 and $200 per acre, three or four times that of sodium chlorate ; nevertheless, farmers willingly pay the difference because the weeds are killed within two or three weeks and the residual effect is brief. Cereals cannot be grown on treated soil in the same season, but beans and some other crops can be planted within three weeks. This is an important consideration on land worth $150 or more per acre.

During the past two years, increasing dependence has been placed on tillage in the Idaho program. County-owned units of a tractor and a cultivator visit the farms in rotation and cultivate each field at the proper time. When well supervised this is the cheapest and best way to exterminate large infestations. About 10,000 acres are now under a tillage program.

In the course of administering their State weed laws, several States are operating weed control programs independently of the Federal government. One of the largest is that of Kansas, one of the most important wheat-growing States in the Great Plains. In 1935, bindweed occupied several hundred thousand acres and was spreading rapidly. By 1937 the situation had become so alarming that the State Legislature enacted a law directing county assessors to ascertain the extent of bindweed infestation on each farm and requiring all landowners to destroy the weeds under penalty of fine. In order to spread the burden of cost and implement the law, county and municipal authorities were empowered to levy a special tax to help defray the cost of eradication. County weed supervisors, under the guidance of a State weed supervisor, were employed to enforce the law.

The plan has been in operation two years with gratifying results. Every effort is made to obtain the voluntary co-operation of the farmers and this has been done in a very large measure. In return, the counties purchase sodium chlorate and other necessary extermination material in wholesale quantities and sell it to the landowners at half-price. Tillage machinery is purchased in large units by the county and loaned to the farmers at cost. The farmers furnish labor and motive power.

By the end of 1939 nearly 100,000 acres of bindweed had been quite or nearly destroyed, and there is reason to expect that much of the bindweed in the State will be brought under reasonable control within the next four or five years.

Other States are giving aid in one form or another to farmers whose weeds are beyond control. The details of operation vary and time will be required to develop the most equitable and workable systems.

In the United States, perhaps more than in other countries, laws and regulations require the background of determined public support. Until people can see and fully appreciate the need for action, performance is likely to make slow progress. A most important factor, therefore, in the success of legislation, research and control alike, is that they be accompanied by a sound program of education. In the United States, this function is ably performed by the State and national Agricultural Extension Services, a highly organized, closely co-ordinated group of agencies through which the findings of the research laboratories are carried out to the farms. In several States, Weed Extension Specialists devote their full time to the dissemination of weed control knowledge. In others, part of the time of the Extension Agronomist or Extension Botanist is given to this work.

Close collaboration between legislators, experimentalists, enforcement officers, educators and farmers is the order of the day in America. Measurable relief from the weed menace is in sight in the near future.

A. S. Crafts and R. N. Raynor U.S.A.

PRINCIPLES OF CHEMICAL WEED CONTROL

INTRODUCTION

Modern agriculture, with its specialized crops and methods, and its gradual mechanization of labor, demands adequate pest control. Though the hoe and the weed knife are traditional, the decreasing numbers of hand laborers and the narrowing margins of profit foretell more efficient methods. Agriculture, following the lead of industry, is resorting to chemical aids. Since the failure, in certain situations, of the older cultural and cropping methods, weed control by chemistry is advancing, especially in the newer districts that practice large-scale farming, machine production, and irrigation.

Naturally California, with its diversity of climates, soils, crops, and weed pests, has led in this adaptation of chemistry to weed control. Examples include the work of Gray on arsenic as a translocated herbicide (1917) and as a soil sterilant (1919*a* and *b*) ; the experiments of Johnson (1928, 1932) with oils on *Tribulus terrestris* (puncture vine) ; more recent research leading to the development of the acid arsenical method (Kennedy and Crafts, 1927 ; Crafts and Kennedy, 1930 ; Crafts, 1933*a* and *b*, 1937) ; wide-scale soil sterilization with arsenic, chlorates and borax (Crafts, 1935*a*, *c*, and *d* ; Crafts and Raynor, 1936 ; Crafts and Cleary, 1936 ; Crafts, 1939*a*, *b* ; Crafts and Rosenfels, 1939 ; Rosenfels and Crafts, 1939) ; and the control of *Hypericum perforatum* with borax and borax-chlorate mixtures (Raynor, 1937) ; the application of the jar method for treatment of *Alhagi camelorum* (camel thorn), (Ball, Crafts, Madson and Robbins, 1936) ; and the adaptation of power-spray equipment to sulfuric acid application (Ball and French, 1935). The investigations being sponsored by the California Agricultural Experiment Station and the California State Department of Agriculture are exemplified by current work on carbon bisulfide diffusion in soils ; on the use of Sinox for selective weed killing in cereals, flax, and pastures ; and on the herbicidal action of various petroleum derivatives. The California Forest and Range Experiment Station has co-operated in studies on prevention of re-sprouting of stumps and on weed control on firebreaks (Ikenberry, Bruce and Curry, 1938). Various private agencies have aided in control of *Scirpus* and *Typha* species (tules) in drainage ditches, in soil sterilization along irrigation ditches, in the perfecting of mechanical methods of application, and in almost innumerable demonstrations.

Such active co-operation has led to rapid development of chemical methods until, at present, technics are available to meet many different conditions, and the need for a broader educational programme is becoming apparent.

Recommendations regarding herbicides are often empirical, involving dosages or spraying methods of limited applicability. To be widely useful, methods should be based upon broad chemical and physiological principles ; should entail a complete understanding of the relations between the environmental factors involved ; and

should be varied to meet specific situations. Only an understanding of underlying principles can equip farmers to use chemicals intelligently.

METHODS OF CHEMICAL WEED CONTROL

For efficiency, control methods must relate to the characteristics of the weeds being treated, to the environmental factors regulating growth and response to the treatment, and to the results being sought. The common methods may be classified under the following headings: (1) contact sprays, including (a) non-selective and (b) selective sprays; (2) translocated sprays; and (3) soil treatments, including (a) temporary and (b) permanent soil sterilization. By comparing and contrasting these methods most of the principles involved in chemical weed control can be reviewed and the more critical aspects discussed.

1. Contact Sprays

1a. Non-selective sprays for seasonal control of all undesirable weed growth.

Contact herbicides kill only the tissues to which they are applied. Almost any soluble chemical in high concentration will kill plant tissue. Consequently any highly toxic compound may be used for contact spraying, cost and convenience being the main limiting factors. The common reagents include oils, acid sludge, acid tar, coal-tar derivatives, and sulfuric acid, besides solutions of salts like sodium arsenite, sodium chlorate, iron sulfate, copper sulfate, sodium metaborate, sodium chloride, and, under certain conditions, ammonium sulfate or phosphoric acid. These are used mainly on annual weeds to prevent seeding. They are also helpful in reducing fire hazard and in destroying the unsightly weed growth that obscures vision on roadsides, harbours insect pests, and nurtures plant diseases.

Oils. Unrefined petroleum products contain toxic compounds that react with protoplasm and kill plant cells. According to Gray (1919*a*), those "constituents of petroleum distillates which are capable of being removed by refining with sulfuric acid are more toxic to foliage than other constituents." In his plot tests, petroleum distillates containing a large percentage of aromatic and cracked oils were most effective as herbicides. Gray and de Ong (1926) found the most reliable laboratory index of toxicity to be the sulfonation test that measures the amount of aromatic and olefin compounds present. Oils containing 40 to 50 per cent of sulfonatable compounds were extremely toxic. These fractions, because of their high content of unsaturates, are chemically active; and their low viscosity causes them to spread and penetrate rapidly.

Although density, in the absence of the sulfonation test, has been used as an index of toxicity of unrefined oils, it is not always reliable, for cracked oils have an abnormally high percentage of unsaturated compounds, and those refined with sulfuric acid are relatively free of them. On the other hand, density may be a measure of the tendency to spread. In general, oils in the gravity range of 25° to 35° B are the most suitable for weed spraying. Lighter oils are usually too volatile, whereas heavier ones penetrate slowly and are difficult to apply.

Smith (1936) gives the specifications for oil used in spraying firebreaks along California highways as follows: "Sp. Gr. (A.P.I.) at 60° . . . . not less than 27° B. Flash-point (Pinsky-Martin closed cup) . . . . not less than 150°F. Viscosity (Sayboldt Universal) at 100°F . . . . not over 50 sec. Distillation, 90 per cent point . . . not over 680°F. Water and sediment . . . not more than a trace."

Various petroleum residues and extracts high in unsaturates are useful herbicides (Gray, 1919*a*; Johnson, 1932). These include acid sludge (the residue from sulfuric acid refining), acid tar (acid sludge with the acid removed or neutralized), and extracts from the Edeleanu process (refinement by means of liquid SO_2)

Where a selective action on different species is desired, as in the control of *Taraxacum officinale* (dandelion) in bluegrass lawns, a distillate low in sulfonatable compounds is sometimes used. For this purpose Loomis (1938) recommends kerosene containing not over 4 per cent unsaturates.

Tucker (1936) suggests that not the unsaturated compounds but asphaltogenic acids resulting from their oxidation in air and sunlight are the toxicants that make oils good herbicides. Unsaturated oils freed from asphaltogenic acids became non-toxic, whereas saturated non-toxic oils became toxic when these acids were added. This fact may explain why oils are more toxic in warm sunny weather. It also indicates that certain unsaturated compounds may be more effective than others.

Oils, being less reactive than strong acids and heavy metal salts, continue to move by capillarity along plant tissues, destroying successively deeper layers of cells. By this deep penetration they can kill the protected growing points of grasses and the seeds of puncture vine (Johnson, 1932).

Diesel fuel oil and other low-priced petroleum derivatives are used in immense quantities for roadside weed control and fire prevention in California. Since the more toxic fractions containing most of the unsaturated compounds are now being sold in heavy fuels, their diversion into weed control would save money besides replacing the Diesel fuel now being applied. This change is highly desirable from the standpoint of conserving our fuel resources.

Dosages of oil sprays vary from 150 to 500 gallons or more per acre, depending upon the height and density of vegetation. The surface of the weeds should be completely covered, and grasses require a thorough application. No advantage has been gained by emulsifying the oils.

Creosote, furfural, and various by-products of the distillation of woods and coal are used as contact sprays, either alone or in mixtures with petroleum oils (Arnold, 1933; Buckardt, 1936; Smith, 1934). They are, as a rule, highly toxic; but being bulky to transport and limited in quantity they are consumed locally and are not important in the herbicide market.

Sulfuric acid. A ready source of hydrogen ions should prove an excellent contact killer of plant tissue, and sulfuric acid is the most commonly used reagent for this purpose. Although still employed against mustards, thistles, and other broad-leaved annual weeds, it has not proved successful against grasses even when used with a spreader. Incorporation of a detergent of the modern sulfonated higher alcohol or dicarboxylic acid ester type will allow dilute sulfuric acid to spread on plant surfaces

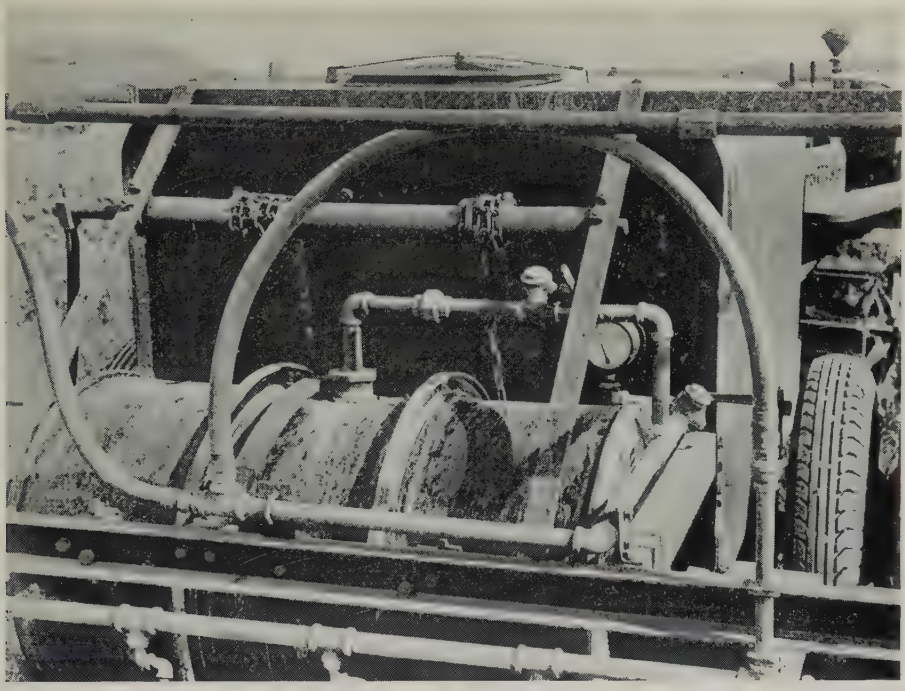

FIG. 1.

FIG. 2a.

FIG. 2b.

FIG. 1.—Rear view of sulfuric acid sprayer, showing water tank (above), and acid drum (below). Water from the pump at the front of the machine passes the pressure gauge and shut-off valve, goes through the ejector, where it picks up acid from the drum. Thence it goes to the rear where it is distributed to the booms via the curved hoses shown.

FIG. 2a.—Sprayed (left) and unsprayed (center) strips in a wheat field. Sinox has completely controlled the wild mustard in the treated strips.

FIG. 2b.—Unsprayed (left) and sprayed (right) strips in a field of flax. The crop was almost a complete failure in the untreated areas.

FIG. 3.

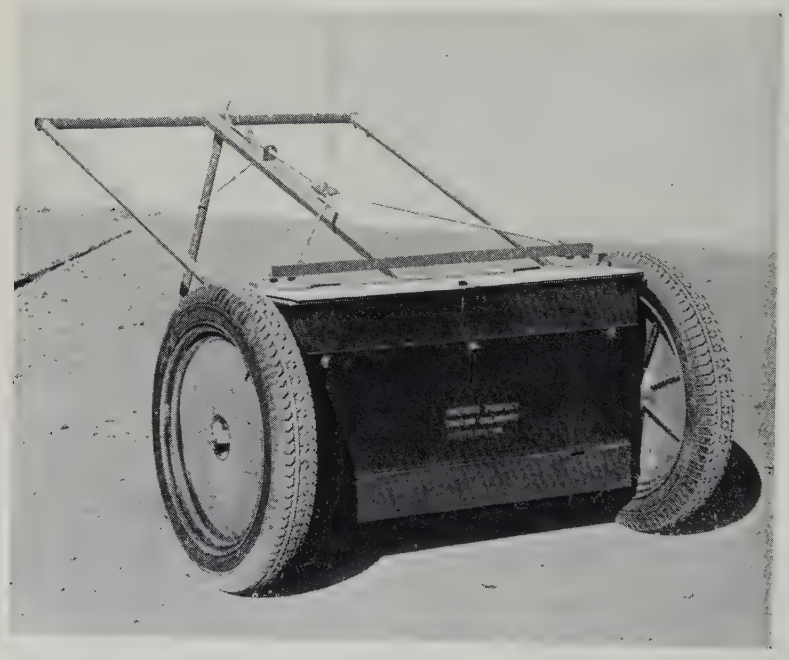

FIG. 4.

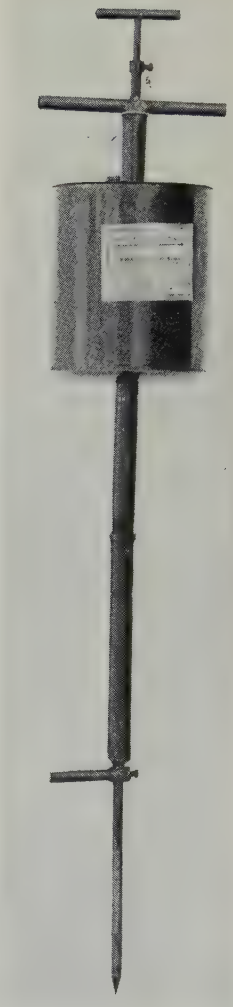

FIG. 5.

FIG. 3.—Front view of a large tractor-drawn sprayer used to apply Sinox in grain fields in California.

FIG. 4.—Applicator for applying dry sodium chlorate to the soil. The rate of application can be regulated by adjusting the control mechanism on the central standard. Manufactured by the Masters Planter Company of Chicago, Illinois, U.S.A.

FIG. 5.—Hand prod for injecting carbon bisulfide into the soil. One stroke of the handle shown at the top forces a measured volume of the liquid through the perforations just above the bevelled tip at the lower extremity. The side arm is used in forcing the prod into the soil with the foot.

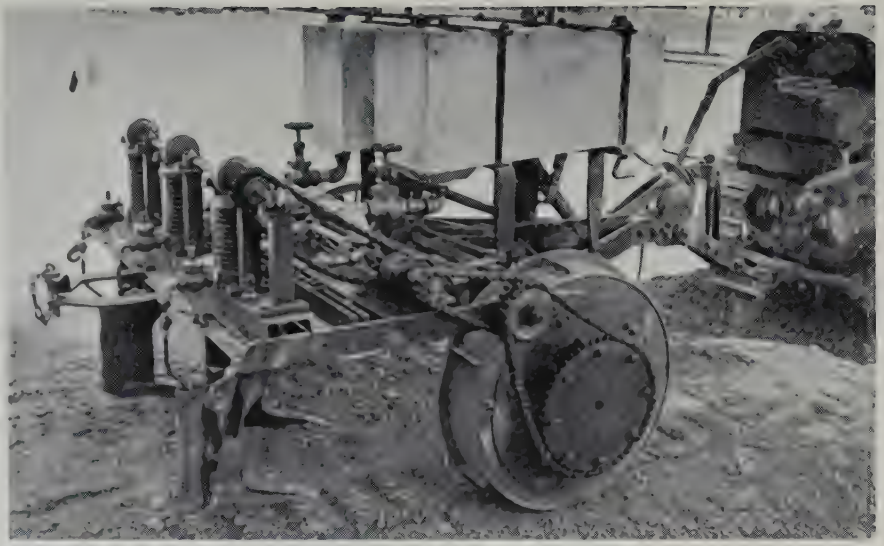

FIG. 6a.

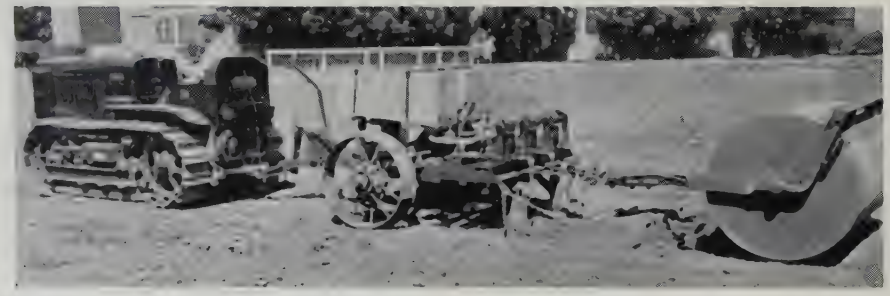

FIG. 6b.

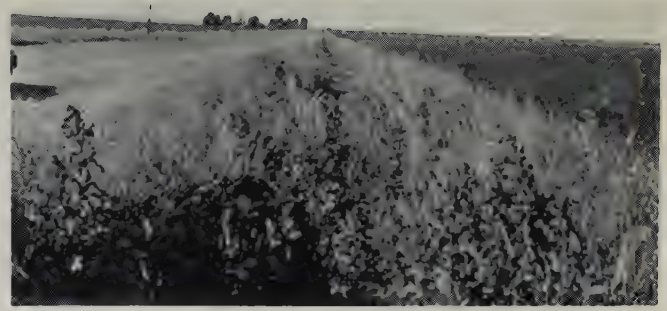

FIG. 7a

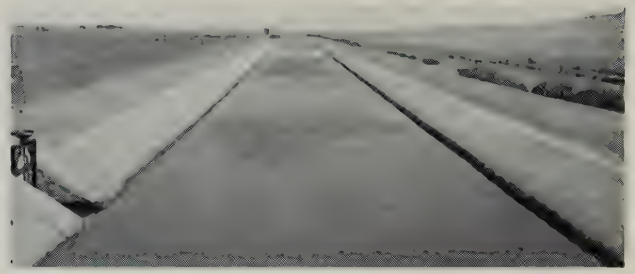

FIG. 7b

FIG. 6a.—Power applicator for injecting carbon bisulfide into the soil. Pipes at the rear of the machine carry the liquid from the mechanically operated pumps into the crevices left by the sub-soiler standards.

FIG. 6b.—Complete power equipment for applying carbon bisulfide. Crevices behind the subsoiler standards are filled by the block drags and rolled by the heavy roller shown. When filled with water this roller weighs about 1,600 lb.

FIG. 7a.—Untreated open ditch near Westley, California. Weeds in this ditch hinder the flow of water and produce seeds that are carried into the fields.

FIG. 7b.—Irrigation ditch lined with concrete and sterilized with arsenic. Weeds seeds, insect pests and plant diseases are reduced to a minimum by this treatment.

almost as effectively as oil (Ball and French, 1935) ; yet grasses are only superficially injured, and the growing points usually survive and continue to grow. The cause, apparently, is the high reactivity of the acid. In contact with plant buffers the hydrogen-ion concentration of the acid spray is rapidly reduced. Penetration is not sufficient to reach the growing points. Increasing the acid concentration not only raises the cost but introduces additional problems in the application. Enough 10 per cent sulfuric acid to wet the plants will kill most broad-leaved weeds ; but this treatment cannot, at present, be recommended for control of grasses.

Sodium arsenite. Time has proved the effectiveness of dilute sodium arsenite solution as a herbicide. It has become the standard " weed killer " for use along railroads, on parking areas, fence lines, or tennis courts, and, although the hazards to livestock and wild life are great, arsenic is still used in immense quantities.

With the present development of mechanical methods of weed control, the introduction of new, less poisonous herbicides, and the demonstrated soil-sterilization technic that practically eliminates the poison hazard in the use of arsenic, there seems to be little need for the continued use of sodium arsenite as a contact spray. Where it can be applied with safety, experiments have shown that the inclusion of a spreader, either whale-oil soap or a modern detergent, will greatly increase its effectiveness on such plants as tules and grasses that are normally difficult to wet.

Many other salts have been and will continue to be used for spraying. The effectiveness of salts in aqueous solution depends upon toxicity and reactivity. Highly reactive compounds usually kill superficially but are relatively independent of climatic variables. The slower-acting reagents may require dew or fog to keep them in solution and are readily washed off by rain. On the other hand, if allowed sufficient time they penetrate deeply and kill more completely. When the operator understands the needs to be met and the variables to be encountered, he can usually select from the salts of heavy metals or of fertilizer elements the most useful herbicide and determine its dosage requirements by simple plot tests. Of merit are salts of copper, chromium, and zinc, besides such fertilizers as ammonium salts, thiocyanates, sulfates, and phosphoric acid or its salts. Sodium metaborate has also been used with success.

1b. Selective sprays

Early work on the selective spraying of mustards in cereal crops involved using iron sulfate, copper sulfate, and copper nitrate. By 1935, emphasis had shifted to sulfuric acid (Ball and French, 1935) ; and now the sodium salt of orthodinitrocresol, sold under the trade name of "Sinox," is entering the field. The latter two reagents were used in large quantities during the current season in California, and each has distinctive advantages.

Sulfuric acid. Large-scale grain growing, the use of the combined harvester which leaves many weed seeds in the straw, and a lack of hand labor have led to heavy infestation of many western areas with *Brassica*, *Amsinckia*, *Centaurea*, *Chenopodium*, and *Atriplex* species that reduce yields seriously. Because of low humidity and high temperatures, iron sulfate and other salts were not successful as

selective sprays; and only with the introduction of sulfuric acid in 1935 (Ball and French) was spraying practical on a commercial basis. If an ejector was placed between the pump and the spray nozzles of a stock orchard spray machine, the concentrated acid could be mixed with water without injury to the pump (fig. 1). A number of commercial machines have been built, and several thousand acres of grain have been sprayed each year. Recently, by using a centrifugal pump built of Durimet (acid-resistant alloy), rubber and brass tubing, and Durimet nozzles with Durimet or porcelain discs, a satisfactory machine has been built to apply the dilute acid pre-mixed in the field. Pre-mixing is advantageous: it saves time and avoids variation in concentration with fluctuating pressures. Spray machines of the acid-resisting type have been used for two seasons with little wear on the pump, few delays from corrosion of parts, and fully satisfactory application of the dilute acid. MacDowall (1938) reports the use of similar acid-resistant metal in acid sprayers in England.

Sulfuric acid kills because of its high hydrogen-ion concentration. It is selective because the cereals are difficult to wet and have their growing points well protected by ensheathing leaves. Being highly reactive, the acid works rapidly and is relatively independent of the climatic variables of humidity, temperature, and wind velocity. For these reasons the sulfuric acid method gives good results under most conditions and will kill mustard even if applied shortly before rain. It has the added advantage of dissolving bases in the soil. When used, therefore, on cereals on the neutral or slightly alkaline soils of the western United States, it reduces lodging and somewhat increases yields.

In contrast to these advantages, sulfuric acid is disagreeable to handle; any drifting of the spray causes discomfort to the tractor driver and sprayer operator. It is rather corrosive to all machinery and requires expensive special equipment. Furthermore, it injures the grain plants somewhat and retards growth appreciably when used in sufficient strength to control certain species of *Amsinckia*, *Centaurea*, etc. Because of these disadvantages of acid, Sinox has been developed and may largely replace the acid as a selective spray.

Sinox. This dinitrocresol salt is a yellow dye, non-poisonous in the ordinary sense, non-corrosive on machinery, and highly selective. Though no work has yet been published to explain its toxic action, it apparently adsorbs on the plant surface, penetrates slowly, causes death of the cells, and eventually fosters a fungous invasion, which results in the collapse of the weeds, sometimes killing large blossoming plants (figs. 2 and 3).

Although less reactive than sulfuric acid, Sinox adsorbs rapidly and will usually destroy the weeds even if followed within 30 to 60 minutes by rain. Killing more slowly, however, its action is more affected by temperature than is that of an acid, and judging from the current season's experience, it should not be used during periods when the maximum daily temperature remains below 50°F.

According to field tests under various meteorological conditions on plants at different stages of growth, weed plants are most easily killed by Sinox sprays when they are growing rapidly under conditions of moderate temperature, high humidity,

and adequate soil moisture. Such plants are succulent and have a thin cuticle, easily penetrated by the spray ; on a warm day translucent spots may appear on the leaves within 30 minutes after the application. On the other hand, plants growing slowly, or not at all, under conditions of low temperature, low humidity, and deficient soil moisture, have a thick cuticle through which diffusion is retarded, especially in cold weather. Such plants, sprayed at low temperatures, may show no necrotic tissue, although after several weeks they may be stunted and chlorotic. In the absence of dew or other external moisture to aid diffusion, the dried spray remains visible on the surface. These observations on Sinox agree with Bolley's (1908) experiences with iron sulfate and other salts. According to Bolley, "succulent plants of a particular species or variety die more quickly than those which are less succulent," and "young, rapid growing plants of a particular species or variety are more easily killed than those which, for any reason, have a slow growth."

Treatments that appeared unsuccessful shortly after spraying have sometimes become effective with improvement in growth conditions, so that the final outcome was satisfactory. Even rain falling before the killing action is complete does not nullify the treatment, provided the material has a chance to adsorb on the plant first. This property of orthodinitrocresol was also observed by Gimingham and Tattersfield (1927) in their experiments with the compound as an insecticide and ovicide. This property of resisting washing off overcomes the slow action of Sinox and makes it superior to slow-acting salts such as copper sulfate and iron sulfate.

More selective than acid, Sinox has proved effective in controlling weeds (other than grasses) in flax. It has also killed *Centaurea solstitialis* (yellow star thistle), *Silybum marianum* (milk thistle), and other broad-leaved weeds in mixed grass pastures without seriously affecting grasses, *Erodium* species, or certain clovers. It offers some promise for controlling dandelions and *Syntherisma sanguinalis* (crab grass) in lawns, and has proved successful in killing *Polygonum aviculare* in onions and *Datura tatula* in maize.

Because Sinox adsorbs rapidly and apparently moves somewhat within the tissues during the slow killing process, it is relatively independent of the concentration-volume relation so important with other herbicides. For this reason it may be applied as a highly atomized saturated solution at a relatively low volume rate and has been adapted to application by aeroplanes with eminent success. Over 2000 acres were treated in this way during the current season in the delta region near Stockton, California ; and excellent results were obtained where the rate of application was kept constant and where distribution was uniform. Since aeroplane and spray-machine application of Sinox and machine application of sulfuric acid are comparable in cost, commercial operators in the grain-growing sections will probably use Sinox during the milder seasons, resorting to acid when temperatures drop below the minimum required for success with the dye. Thus they can operate throughout most of the winter and spring—an obvious advantage from the financial standpoint. In California, because of the low humidity, cyanamid, kainite, and other toxic dusts have proved less effective as selective herbicides. In other regions, apparently, they are useful and have the added advantage of a residual fertilizer value.

The high selectivity of Sinox toward the thistly type of weeds in pastures is encouraging, since this is the first herbicide that combats these weedy invaders without disturbing the sod and upsetting the balance of established species in these areas. In this connexion one should note that the unirrigated valley and foothill pastures of interior California are populated chiefly by introduced annual brome grasses, *Erodium* species, burr clover, native *Trifolium* spp. etc., which are not competitive enough to keep out the *Centaurea* and *Silybum* species under moderate to heavy grazing. The gradual spread, therefore, of the thistly types is a serious menace ; and a chemical method offers almost the only practical technic for improving these pastures.

2. Translocated Sprays

Gray (1917, 1919*a*) first observed that a dilute arsenic solution sprayed on *Convolvulus arvensis* (morning-glory, bindweed) would move down through the plant tissues and kill the roots several feet below the surface of the soil. Subsequent work (Kennedy and Crafts, 1927 ; Crafts and Kennedy, 1930 ; Crafts, 1933*a* and *b*, 1937 ; Morgan, 1931, 1935) explained the mechanism by which herbicides may be translocated in plants. Briefly, when water loss by transpiration exceeds water absorption by roots, a deficit is developed throughout the plant ; and water rising through the xylem may be under sub-atmospheric pressure or actually in a state of tension. When a plant in this deficient state is cut under a solution at atmospheric pressure, the solution is drawn in rapidly and, moving through the conducting elements of the xylem, is translocated back into all intact parts of the plant to satisfy the needs of the living tissues. Likewise when the foliage of a water-deficient plant is sprayed with a solution of a strong acid or base, the living cells are killed and rendered permeable ; and the sap from these, being freed from osmotic forces, is drawn rapidly down into the roots. If the spray solution contains a toxic substance, such as arsenic, that can move freely through killed plant tissue, this substance will diffuse into the cells, become incorporated in the sap, and eventually be carried in the backward-flowing stream. Distributed through the root system, it kills the living cells of the cambium and storage tissues. In time the sprayed foliage is destroyed, the tissues become dry, and downward movement in the xylem stops. The various limitations upon the action of this mechanism have been described in the publications cited.

According to experiments, an acidified dilute solution of sodium arsenite sprayed after sundown on the foliage of morning-glory plants in the proper water-deficient state will sometimes kill 95 per cent of the roots to a depth of 4 feet. The standard volume-rate of application is 3 gallons per square rod ; and the optimum acid concentration is 1.0 normal (approximately 5 per cent by weight). Arsenic concentration in terms of As_2O_3 should be $\frac{M}{20}$ to $\frac{M}{40}$ (1.0 to 0.5 per cent by weight) (Crafts, 1933*a*) depending upon the volume to be applied. Application between sundown and midnight has proved best ; the plants should have a maximum top growth ; and the soil should be relatively low in available moisture (Kennedy and Crafts, 1927 ; Crafts, 1933*a*). Although a subsequent spray with water early on

the morning after the spray application is one means of improving the results of the acid-arsenical method, probably it is better to use increased volumes of spray solution up to 6 gallons per square rod (Crafts, 1937). Where this is done, the arsenic concentration may safely be dropped to 0.5 per cent by weight ; but the acid concentration should be maintained.

Though inexpensive and convenient, the acid-arsenical method is limited by natural variables. Uniform maturity is uncommon in areas of weeds variable in density and growing on non-uniform soils. Genetic variations also alter uniformity, and differences in root penetration and soil-moisture content affect the plants. Injury by rodents or insects incapacitates the translocating mechanism, and severe drought may limit root development in any one season to a relatively shallow layer of top soil.

Despite these drawbacks, the method has proved valuable and promises to be even more useful as a pre-treatment for chlorate or carbon bisulfide application (Crafts, 1937) and as a combination with cultural or cropping treatments. Best results have been obtained on *Centaurea repens* (Russian knapweed) and moderate results on *Convolvulus arvensis* (morning-glory) and *Sida hederacea* (alkali mallow). *Lepidium* species (hoary cress), however, will not translocate arsenic satisfactorily ; and the perennial stoloniferous grasses do not respond. Special acid-resistant equipment is not required for applying the acid-arsenical spray, for arsenic reduces the corrosive action of sulfuric acid on iron (Crafts, 1933*b*).

Studies show that sodium chlorate, if applied in solution as a spray, will penetrate plant tissues and be translocated into the roots (Crafts, 1935*b* and *d*). It will also kill weeds when absorbed from the soil by the roots (Aslander, 1928 ; Loomis, Bissey and Smith, 1931 ; Loomis, Bissey, Smith and Arnold, 1933 ; Muenscher, 1932 ; Crafts, 1935*b* and *d*). As a translocated spray, chlorate is subject to the same limitations as the acid-arsenical spray. Through the soil, however, it affects all roots present and, if thoroughly distributed, will give more satisfactory results. Naturally, where one is interested in killing deep-rooted perennials in an orchard, vineyard, or garden, it will not take the place of the acid-arsenical spray. (See, however, Pieper and Hackleman, 1937 ; Beach, 1938 ; and Willard, 1938, who cite instances where chlorates have been used in orchards without severe injury to the trees.) Under certain conditions, killing both through the plant and through the soil can be utilized, with excellent results. In regions of frequent summer rains it is difficult and not important to distinguish between the action of translocated chlorate and of that absorbed by roots. In California, on the other hand, this distinction is easy, and the superiority of the soil-application method has been well established. Chlorate is used most logically as a translocated spray only where the poison hazards of arsenic make the latter prohibitive.

Sodium arsenate, arsenic acid, sodium bisulfite, ammonium thiocyanate, acidified copper sulfate, and sodium and calcium hypochlorite-chlorate mixtures are translocated to some extent in plants. Oils, if repeatedly sprayed on certain grasses, kill the roots to a considerable depth, and translocation is probably by a capillary or wick action. At present, apparently, the acid-arsenical solution recommended by this station is the most effective herbicide of this type.

3. Soil Treatments

3a. Temporary soil sterilization

Chemicals that kill plants when absorbed from the soil by roots and that decompose, evaporate, or leach readily have been termed temporary soil sterilants. Three solids—sodium chlorate, ammonium thiocyanate, and borax—come within this category ; and two volatile liquids—carbon bisulfide and chloropicrin (tear gas) —are effective herbicides.

The possibility of exterminating plants through the soil depends upon several factors. Whereas some plants are easily killed by any means, others require drastic treatment. Species vary widely in their susceptibility to chlorate injury, and dosage recommendations ranging from a few pounds to over 1,000 lb. per acre have been noted. Ammonium thiocyanate is more effective on some weeds than upon others under identical soil conditions. Besides differences in susceptibility inherent in plants, certain soil factors influence the effectiveness of temporary sterilants in a major way. To determine the responses of weeds to soil sterilants one must recognize these various regulating factors and integrate them on a sound basis (Crafts, 1935*d*).

Sodium chlorate. Within the past ten years sodium chlorate has assumed a major position among chemical herbicides (fig. 4). Chlorate toxicity is affected by soil type, which regulates moisture penetration, and by salt concentration, particularly that of nitrates. According to recent experiments (Crafts, 1939*a* and *b*), chlorates are less toxic in fertile than in poor soils ; and this phenomenon has been related to the fact that chlorates are not readily absorbed from soils having high nitrate concentrations (Crafts, 1939*b*). Chlorides and sulfates in large quantities also reduce chlorate absorption, but less effectively than nitrate. For these reasons, fertile soils and saline soils require high chlorate dosages ; and where chlorate-tolerant plants such as the hoary cress species (*Lepidium* and *Hymenophysa*) infest rich or saline arid soils, chlorates may be almost totally ineffective in their control.

Both soil-moisture distribution and nitrate concentration may affect chlorate toxicity in regions of low rainfall. When the total annual rainfall wets the soil to a depth of a few feet only, chlorate applied to weeds is restricted to this moist zone, and nitrates accumulated through the dry season are concentrated in the lower portion of this layer. The killing action of the herbicide may be restricted, consequently, to the top foot or two of soil ; and sprouts from below this region can survive. In regions of ample rainfall, particularly those of frequent summer rains, chlorates are rapidly distributed throughout the region of root penetration, and nitrates have no opportunity to accumulate. For this reason a chlorate application of about 1 lb. per square rod may eradicate morning-glory in one region and yet have little effect in another. Although the general recommendation for chlorate application ranges from 1 to 3 lb. per square rod, the above discussion indicates that dosages necessary for satisfactory results actually vary much more widely ; not only weed species and climatic factors, but also soil texture and fertility must be considered.

Judging from experiments, chlorates disappear from the soil both by decomposition and by leaching (Loomis, Bissey, Smith, and Arnold, 1933 ; Bowser and

Newton, 1933 ; Crafts, 1935*c*). In arid regions, with little or no summer rainfall, leaching is the predominant factor ; chlorate spots may persist in fields for years if the rainfall is light (Crafts, 1935*c*). In regions of summer rains, decomposition and leaching both occur, and crops are often grown on treated areas within a few weeks after chlorate application. Repeated irrigation is the most effective means of reclaiming chlorate spots in the arid western soils (Crafts, 1935*c*).

Ammonium thiocyanate. Ammonium thiocyanate, used in numerous experiments, has nevertheless not attained commercial prominence as a herbicide. Though extremely toxic as a contact spray, it costs more than Diesel oil, dilute sodium chlorate, or sodium arsenite. It is less effectively translocated than the acid-arsenical spray or sodium chlorate. As a temporary sterilant it has offered promise in some regions, but is less effective than chlorate in California.

In the soil, ammonium thiocyanate is retained in the top few inches and is therefore effective only against shallow-rooted perennials. At rates of 4, 8 and 12 lb. per square rod, it controlled *Hypericum perforatum* (St. John's wort) successfully (Raynor, 1937), but the cost was prohibitive. Offord (1939) found it particularly effective against certain *Ribes* species in acid forest soils ; and quantities of it have been used in this work. Being repellent to livestock, commercial ammonium thiocyanate has been useful for controlling thistles in pastures in the more humid states. In California it apparently has no place in the chemical weed-control programme. Sodium thiocyanate is subject to the same objections as the ammonium salt.

Borates. Although borax will be discussed in the following section as a permanent soil sterilant, in regions of high rainfall it is leached rapidly enough to be called only temporary. Borax and boron ores, both alone and combined with sodium chlorate, have proved effective in controlling *Hypericum perforation* (Raynor, 1937) and *Chamaebatia foliolosa* (Ikenberry, Bruce, and Curry, 1938). These weeds, native to humid habitats, are limited, in the western United States, to regions of 25 or more inches of rainfall.

Being weakly retained in soils, borates remain effectively concentrated in the top soil during the incidence of the first 4 to 10 inches of rainfall. Additional precipitation lowers the concentration and makes the chemical less effective in killing shallow-rooted perennials (Raynor, 1937). Borate toxicity has been shown to be related to textural grade of the soil (Crafts, 1939*b*), being low in heavy and high in coarse soils. Retention is also greatest in heavy soils (Crafts and Raynor, 1936), and the problem of penetration with respect to the depth of the root system requires careful consideration of rainfall and soil type. As Raynor (1937) has pointed out, the time of application must be related to these factors if optimum results are to be obtained from chemicals.

Recent reports from Idaho and Washington indicate successful use of borax and borax-chlorate mixtures on morning-glory and other deep-rooted perennials. Similar tests at Davis, California, showed borates to be ineffective against *Convolvulus arvensis* and *Sida hederacea* in dosages up to 16 lb. per square rod. Evidently soil and climatic factors materially alter the response of perennials to boron compounds. Since these chemicals are just coming into use as herbicides, a thorough testing programme is needed to explore their possible value in weed control. There are in-

dications that weeds growing in leached soils and adapted to low salt concentration will give the most marked responses to boron compounds.

Carbon bisulfide. The vapors of carbon bisulfide and chloropicrin are apparently toxic to all plant cells and, if released in the soil in sufficient quantities, will kill deep-rooted weeds. Carbon bisulfide has been used successfully for many years for controlling *Convolvulus arvensis*, *Centaurea repens*, and other deep-rooted perennials in the western United States (Rogers and Hatfield, 1929; Frost, 1932; Ball, Crafts, Madson, and Robbins, 1936). Contrary to common opinion, this material is not prohibitively expensive when used to control limited areas of weeds which are interfering with crops and jeopardizing future production on adjacent clean lands. Within the past five years, thousands of tons have been used for weed control in the western United States; and this chemical will continue to be employed as long as noxious weeds reduce yields on the more productive lands in this region.

The standard practice in using carbon bisulfide, developed through years of empirical testing, has been to apply the liquid in 2-ounce doses in holes 8 to 12 inches deep, spaced 18 inches apart in the soil. Various tools have been developed for applying the chemical, including a mechanical hand prod with a measuring force pump (fig. 5), and a power equipment for large-scale application (fig. 6), (French, 1939), both of which have proved convenient and practical. Judging from current research on the diffusion of carbon bisulfide in soils (Hagan, unpub. ms.), distribution of the vapor is affected by soil moisture, compaction, and textural grade. A moist or highly compacted surface layer has proved essential to the retention of the vapor within the soil mass. It is hoped that this research will provide a graded series of dosages to meet all soil conditions and to replace the universal dosage now recommended. Results should then be improved and savings effected in many soils.

Chloropicrin. The chance observation that chloropicrin sterilization intended to clear soils of certain insect pests and pathogenic fungi will also kill weeds and weed seeds has led to the increasing use of this material (Godfrey, 1939; Godfrey, Oliveira and Hoshino, 1934; Rhode Island Expt. Sta. 1937; Monteith and Rabbitt, 1939). With expanding markets to reduce production costs, this toxicant may perhaps be added to the list of chemicals available for weed killing. Although we cannot yet predict its future, any temporary soil sterilant of a vaporous nature that will kill rapidly and leave the soil free for crop production within a relatively short time is an ideal herbicide for controlling deep-rooted perennials and should be thoroughly tested.

3b. Permanent soil sterilization

In most agricultural and industrial regions there are places where any plant growth is objectionable—for example, railway roadbeds, irrigation ditchbanks, mill yards, parking areas, aerodrome fields, and playgrounds. Chemical treatments to free such areas of weeds reduce the need for hand hoeing, weed knifing, burning, etc. Such treatments have been studied in California, and directions formulated for sterilizing soils under many conditions. Most useful among the materials tested have been sodium arsenite, arsenic trioxide, borax and borate ores, and sodium chlorate. The choice of a particular material or combination of materials is

determined by the weed species, the soil type, the climate, and by the results desired.

Sodium arsenite. Applied in a solution containing approximately 5 per cent As_2O_3 by weight, sodium arsenite has been most widely used. Sprayed on the bare soil during the winter, this material will free the treated areas from all plant growth for one or more seasons (Gray, 1919*a* and *b* ; Crafts, 1935*a*). Careful handling almost eliminates the poison hazard and, according to numerous tests, results show the method to be entirely practicable (fig. 8).

Experiments with 80 typical California soils (Crafts and Rosenfels, 1939) show that arsenic toxicity is determined largely by textural grade. Briefly, these results indicate that practical sterility is attained with 200 parts per million of As_2O_3 in sands, 350 ppm. in gravelly and sandy loams, 400 ppm. in loams, 550 ppm. in silt and clay loams, and 800 ppm. in clays. Reddish soils characterized by kaolinic clays render much phosphorus unavailable (Murphy, 1939) and require heavier applications than do other soils of comparable texture. Arsenic likewise is made unavailable in such soils, and dosages must be high to effect sterilization.

Retention of arsenic against leaching by moving water, but in a form available to plants, also depends upon texture. In heavy soils, arsenic is likely to stay in the top layer, while in sandy soils of granitic origin it may penetrate deep enough to kill shallow-rooted perennials after precipitation of 6 to 20 inches (Crafts, 1935*a* ; Raynor, 1937). Arsenic is slowly rendered unavailable to plants, and this change takes place to a relatively greater extent in light soils than in heavy (Crafts and Rosenfels, 1939).

Although the interrelation of these various factors seems complex, the practical method of meeting the requirements for soil sterilization is to apply sodium arsenite solution to the soil at a rate equivalent to 4 lb. arsenic trioxide per square rod and then repeat the treatment as often as is necessary for maintaining the sterile condition. According to tests, this procedure may be required only once in four or more years on light soils in semi-arid regions, and more frequently up to annually on heavier soil types or with heavy precipitation. The soil tends to become saturated with arsenic so that later applications will be increasingly effective. There are also definite indications that re-treatment with dry arsenic trioxide will give more lasting results per unit of arsenic than re-treatment with the soluble arsenite.

In using sodium arsenite for soil sterilization, one should make the application early in the rainy season, or at a time when the soil is relatively dry and can absorb moisture rapidly. At such times the chemical is soon washed into the soil, where it is absorbed and presents little or no poison hazard. When, however, there is standing water on the soil, pools of dilute sodium arsenite attract livestock, and the poison hazard becomes acute. If the chemical is applied to a soil saturated with moisture, further rains, particularly if torrential, will wash away the top soil containing it ; and not only will the treatment fail in the area of application, but the arsenic may injure plants wherever the soil is deposited. Finally, sodium arsenite should be applied only to clean, bare soil, for if mixed with vegetation, either dead or alive, it is adsorbed and renders this vegetation poisonous and attractive to livestock, presenting an intense hazard.

Sodium chlorate may be included in the sodium arsenite solution for soil sterilization where deep-rooted perennials are present. The dosage should be practically identical with that for the chlorate treatment alone, as previously discussed.

Arsenic trioxide. Dry white or gray arsenic just as it comes from the smelters may be used for soil sterilization. Being only slightly soluble, it requires some time to concentrate sufficiently in available form within the top soil layer to kill seedlings. Consequently, if immediate results are desired, one must add 10 to 25 per cent sodium chlorate and apply the mixture, or use a preliminary treatment with sodium arsenite and follow with the dry arsenic. Sterility thus produced is more lasting than where the more soluble form is used. For this reason the dry treatment is recommended in regions of heavy rains, for fine-textured soils, and in inaccessible places where the cost of application is high.

The arsenic trioxide treatment has one further advantage: the dry material has—as far as we can determine—no attraction for livestock and can be used with less hazard than the solution. Once incorporated in the top soil it is inaccessible to animals and presents no further hazard.

Borates. Boric acid, borax, and such borate ores as Colemanite, Gerstley crude (a mixture of Kernite and Tincal), and others high in B_2O_3 will sterilize soils if applied in sufficient quantities. Being more soluble and less firmly fixed in the soil, the borates are less lasting than arsenic; but repeated applications will produce a fairly permanent sterility. The obvious advantage is that these materials are not poisonous to animals and can be used on playgrounds, airports, race tracks, and other public areas with no hazard to human life.

Toxicity of the borates is determined by the textural grade of soils, being high in coarse soils and low in heavier grades (Crafts and Raynor, 1936). Borates are retained in the soil against the leaching action of moving water, but less firmly than arsenic. They, too, lose toxicity by long contact with the soil. Again the practical expedient is to make annual or more frequent applications of the borate sterilant until a residual sterility of some duration is attained. Then the dosage may be reduced, or the interval between applications increased. Dosages of 4 to 8 lb. per square rod are indicated on most soils. The addition of 10 per cent sodium chlorate markedly increases the initial toxicity of a borate sterilant and may be required where boron-tolerant species, such as the weedy brome grasses, are present.

Finely ground borate or borate-chlorate mixtures may be applied dry by hand or with a small fertilizer or herbicide spreader. These chemicals must be used cautiously around susceptible trees and shrubs, for the leaching of relatively small amounts into the feeding zone of such plants may cause injury or death.

Chlorates. The permanence of a chlorate treatment to the soil depends largely upon the leaching to which it is subjected. In heavy soils of semi-arid regions and in lighter soils where rainfall is very low, chlorate toxicity may be evident for many years (Crafts, 1935*c*).

Under these conditions chlorates are practical soil sterilants. Under all soil conditions they are effective against deep-rooted perennials provided salt concentrations do not too seriously interfere with absorption. Practically, they are most

effective in combination with arsenic or borates where they give quick temporary sterilization, or where they penetrate and effectively kill deep-rooted perennials. Under all conditions chlorates are potentially dangerous; they should be used with due caution and only by persons familiar with their properties.

4. Special Methods

Besides the general methods discussed above, several special methods are valuable. The following are successful in California.

Weed burning

Although the burning of green vegetation with "weed torches" has proved expensive, laborious, and impractical, fuel oil is commonly used to aid in the burning of such dry vegetation as results from contact spraying with Diesel oil along highways. When the sprayed vegetation is completely dead and dry, it is usually burned before the surrounding unsprayed growth is dry enough to burn. Often, where the vegetation is sparse, a small stream of oil is played on the fire to carry it across bare areas and to keep it hot so that a clean burn will be obtained. In this practice the inner disc from the spray nozzle of a portable sprayer is removed, leaving only the one disc with a single round hole in it. By pumping oil through this simple orifice, a thin straight stream several feet long is produced. Aided by such an oil stream, the fire may be controlled at will and rapidly carried along the front of the area to be burned. Only Diesel fuel or some similar heavy oil should be used. Knapsack sprayers with trombone pumps are commonly used to apply water in fire fighting.

The jar method

A modification of the translocated spray method common among berry growers and gardeners is the "jar" or dipping method (Ball, Crafts, Madson, and Robbins, 1936; Harris, 1939). In this the tops of the weeds are simply bunched and pushed into a glass jar or tin can, which is then filled with dilute sodium arsenite solution (1.0 per cent As_2O_3 by weight) or a 10 per cent sodium chlorate solution. As the foliage is killed, the herbicide solution is drawn back down into the roots and often kills them for some distance underground, particularly if there are leafy branches at some distance to pull the solution into the dipped tops. This method has proved extremely effective in eradicating infestations of *Alhagi camelorum* (camel thorn) in California, because this weed grows in large patches, the plants of which are intimately inter-connected by horizontal rhizomes (Ball, Crafts, Madson, and Robbins, 1936.)

Stump killing

To destroy the stumps of felled trees is often difficult, and experiments have proved the usefulness of chemicals in this work. Large old stumps are often killed by boring many shallow, downward-sloping holes around them near the ground line and filling them with 5 per cent sodium arsenite solution, 10 per cent

sodium chlorate solution, or carbon bisulfide. After treatment the holes should be plugged with mud.

A method widely used by the forest service in killing stumps on firebreaks (Ikenberry, Bruce, and Curry, 1938) is to girdle the stumps at the ground line or just below, cutting just through the bark at an angle and leaving the protruding chips in place. The crevice between the woody trunk and the attached chips is filled with 5 per cent sodium arsenite or, where a poison hazard exists, Diesel fuel oil. The herbicide, penetrating quickly into the injured tissues, kills the cambium tissue and bark to some distance below the soil line. This is sufficient to destroy most tree species. This method has been used on sprouting stumps along many miles of firebreak in California.

CONCLUSION

The foregoing pages describe many methods by which chemicals may be successfully used in weed control. One purpose is to emphasize the great number and variety of the technics developed. Many more, doubtless, will be presented by other contributors. The primary object of this paper is to point out the ways in which the scientific method has been used in solving practical agricultural problems and to enumerate the resultant methods. Probably the greatest immediate need is to acquaint farmers with these methods and so bring them into general practice. For the experimenter, on the other hand, there remain many unsolved problems and many needed improvements. The broader principles underlying herbicidal action have been rather well worked out. There remains the search for new and better herbicides, the more careful elucidation of the mechanics of their action, and the development of improved technics for their accurate and reliable use.

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John Monteith, Jr. U.S.A.

WEED CONTROL IN TURF

The control of weeds continues to be one of the most perplexing problems for the turf culturist. On turf a uniform grass cover is required, and any plant which invades this cover is more or less undesirable. Such invasion is particularly undesirable when the grass is choked out by a dense mat of other plants, as is the case with so much of the weed growth in the United States. The weed problem on turf differs decidedly from that on cultivated fields and, to a less extent, from that on pastures.

In fields planted to farm crops, weeds usually obtain their best growth after cultivation has ceased or after crops have been harvested. Tall-growing annuals mature freely in tilled fields after the last cultivation. In grain fields after the crops have been harvested, both annuals and biennials mature freely in the absence of competition from crop plants and thus keep the ground abundantly supplied with seed.

Many weeds are common to both pastures and other turfed areas. Such weeds as the chickweeds (*Stellaria* spp.) and crabgrass (*Digitaria* spp.) are particularly troublesome in turf, but are not serious in pastures because livestock graze them and thus keep them under control. Other plants such as white clover (*Trifolium repens* L.) are regarded as distinctly objectionable weeds in certain turfed areas, but are recognized as valuable plants in pastures.

Many tall-growing weeds as, for instance, Canada thistle (*Cirsium arvense* (L.) Scop.), which are able to grow to maturity and multiply to a troublesome degree because livestock refuse to graze them, are automatically held in check in turf by frequent mowing. It is interesting to note that the plants which L. W. Kephart lists in his accompanying article as the principal agricultural weeds in the United States are, with very few exceptions, of no importance as turf weeds.

On turf, the weeds must not only compete successfully with the turf grass throughout their entire life cycle, but they must be able to adapt their habit of growth to constant short cutting. The rosette-forming and mat-forming plants are particularly serious turf weeds because their growth habits enable them to develop to maturity under close cutting. Hence, plants that may be considered of minor importance as field or pasture weeds may be of major importance in turf. Other plants, such as white clover and other legumes which are valuable in pastures, may become objectionable in certain turfed areas, particularly those that are used for sports.

The differences of climate in the northern and southern sections of the United States have necessitated the use of two radically different types of grass. The turf in the North is composed mostly of Kentucky bluegrass (*Poa pratensis* L.) or bent grass (*Agrostis* spp.), which grow best in the spring and the fall, and become distinctly

less aggressive or even dormant during the hot summer period. In the South, the Bermuda and carpet grasses (*Cynodon dactylon* (L.) Pers., *Axonopus compressus* (Schwartz) Beauv., *A. affinis* Chase) make their best growth in the hot summer months and are dormant in the winter. In the region between these two sections of the country, it is more difficult to produce an excellent turf, as in this section the grasses best suited to the North or those best adapted to the South do not produce so vigorous a turf as they do in the areas to which they are better adapted. Many weeds grow best during the seasons when the turf grasses are least aggressive and consequently become serious turf weeds. In general, therefore, the weeds which are most troublesome in northern turf are different from those in the South.

The weed problem is most serious in the middle region, where climatic conditions are likely to be unfavourable to both northern and southern grasses. Here the crabgrasses flourish during the summer months. Unless a fairly dense stand of permanent grasses is present, the crabgrass grows so prolifically that it frequently smothers out the bluegrass. In the fall after the crabgrass has been killed by frost, brown, unsightly areas of dead crabgrass are present in the turf. Usually these areas are then filled in by chickweed, clover and other turf weeds.

There is more or less overlapping of the grasses in the middle region. However, because it retains its green color over a much longer season, Kentucky bluegrass is preferred in most of this region. Bermuda grass frequently occurs in large patches throughout areas of Kentucky bluegrass turf. In the winter when the Bermuda grass is dormant, these areas appear as large brown undesirable spots in the areas of green turf. Frequently these patches of Bermuda grass winterkill and leave bare areas which are soon invaded by weeds. Thus, while Bermuda grass is the most common turf grass in the Southern States, it is highly undesirable and regarded as a weed farther north.

Some crabgrass is present in our northernmost section, but it is not the serious problem that it is farther south. In this northern region, such weeds as chickweeds, clover (*Trifolium* spp.) and plantains (*Plantago* spp.) are as troublesome as they are farther south, while others such as dandelions are even more troublesome. In the Southern States where Bermuda grass thrives best, it is able to compete successfully against crabgrass and other summer annuals. In that region the winter weeds become most abundant.

Not only is the weed problem influenced by extremes of temperature, but also by extremes in rainfall. In some southern States frost seldom occurs, while in many Northern States the winter temperatures frequently reach 0 to 15°F. The summer temperatures in both these regions frequently reach 90 to 100°F. and locally much higher.

In many regions the turf grasses may suffer badly from extreme drought in one year, while in the next year the same turf may be subjected to frequent drenching which literally drowns the grass. Such extremes of temperature and rainfall naturally weaken the grasses and encourage many diseases, resulting in severe thinning of the turf and opening the way for many weeds to come in with little competition.

Troublesome Turf Weeds

In America perhaps the most troublesome turf weeds over the largest area are the two species of crabgrass (*Digitaria ischaemum* (Schreb.) Muhl., *D. sanguinalis* (L.) Scop.). These are both summer annuals thriving only in hot weather, but during summer they make such a luxuriant growth as seriously to injure the permanent turf grasses. After the crabgrass is killed by frost, unsightly bare areas in the turf remain. These bare areas then provide ready access to winter weeds such as chickweeds and speedwells (*Veronica* spp.) and thus further aggravate the condition of the turf. Another grass less common but often serious locally is goosegrass (*Eleusine indica* (L.) Gaertn.)

Almost equally objectionable in sports fields, but not on all turfed areas, is white clover, though this does not damage the grass among which it grows so much as does crabgrass. Other serious weeds of almost universal distribution are dandelion (*Taraxacum officinale* Weber) and species of *Plantago*. In some sections the dandelion is a weed of major importance and crowds out much of the grass. Plantains (*Plantago lanceolata* L., *P. major* L.) are generally distributed in the United States and when abundant make serious inroads on turf.

Annual bluegrass (*Poa annua* L.) takes complete possession of many turfed areas. Although this species makes a satisfactory turf, it is objectionable since it is difficult to maintain in good condition throughout the year.

Chickweeds, common (*Stellaria media* (L.) Cyrill.) and perennial (*S. graminea* L.), are often serious, but are more easily held in check than the other weeds mentioned. Mouse-ear chickweed (*Cerastium vulgatum* L.) and various speedwells may be troublesome, and in certain localized areas lawn pennywort (*Hydrocotyle rotundifolia* Roxb.) and pearlwort (*Sagina procumbens* L.) are among the most persistent and hard to eradicate. English daisy (*Bellis perennis* L.) and velvet grass (*Holcus lanatus* L.) are serious turf weeds on the Pacific Coast, but seldom elsewhere in the United States. Nutgrass (*Cyperus rotundus* L.) is one of the most serious weeds in the South, not only in cultivated fields, but in turf. Its habit of forming underground tubers makes it almost impossible to eradicate from large areas.

Besides the above, more or less trouble is experienced from many other weeds which locally may give serious trouble (*Allium vineale* L., *Euphorbia maculata* L., *Hieracium aurantiacum* L., *Muhlenbergia schreberi*, Gmel., *Oxalis stricta* L., *Paspalum laeve* Michx., *Polygonum aviculare* L., *Prunella vulgaris* L., *Ranunculus repens* L., *Rumex acetosella* L., *R. crispus* L.)

Sources of Weeds in Turf

In considering the sources of weeds in turf it must again be pointed out that conditions on turfed areas differ from those on cultivated fields. A weedy field may be fallowed, a smother crop may be planted, or the field may be plowed in preparation for the following crop before the weeds ripen seed. In turfed areas these practices are not possible. Control of weed infestation must be practised without disturbing the turf.

While certain weeds, if already present in turf, may spread by stolons or rhizomes,

new infestations are usually by seed. Weed seeds are universally distributed in untreated topsoil, where they may remain dormant for years. When brought to the surface by cultivation, by disturbing the soil in limited areas, by the action of worms in throwing up their casts, or by other means, they are able to germinate as soon as environmental conditions permit.

Weed seed may be carried by wind singly as in the case of the dandelion, or attached to portions of plants, as in certain grasses. They may be carried by run-off waters, which may be of local concern, as wash from bunkers on to putting greens, or may cover large areas.

Weeds may also be distributed by human agencies. Seeds or portion of plants may be scattered by the rotary mowers or may adhere to other tools and thus be carried from place to place.

A fertile source of weed seed is contaminated compost. Most compost is likely to contain weed seed. Studies by the Green Section have shown that it is not unusual to add 70,000 weed seed to a putting green in a single top-dressing. While it is seldom practicable to control the distribution of weeds by wind or by run-off water, their distribution by top-dressing can be controlled by using only sterilized compost. Stable manure when used on turf also may be a prolific source of weeds.

Perhaps the most fertile source of weeds in turf is the use of impure grass seed. A few weed seeds are usually found even in well cleaned grass seed, and in the poorly cleaned samples they may be very abundant. Some weeds known to be distributed in this way are mouse-ear chickweed, yarrow (*Achillea millefolium* L.), self-heal (*Prunella vulgaris* L.), sorrel (*Rumex acetosella* L.), buckhorn plantain (*Plantago lanceolata* L.), and species of speedwell. Timothy (*Phleum pratense*), which is objectionable in Kentucky bluegrass turf, is usually introduced as an impurity in Kentucky bluegrass seed.

In agricultural plantings the source of seed is usually not an important factor, but for turf purposes seed is used so much more freely than in seeding agricultural grasslands that weed seeds are applied more abundantly, and become a serious factor.

Maintenance Methods Discourage Weeds

Regardless of the source of the weed seeds, the resulting seedlings cannot make a vigorous growth in a dense turf where competition for root space is acute and where shade becomes a limiting factor for the emerging plants. One of the best methods for minimizing the problem of weed control in turf, therefore, is to establish and maintain a dense stand of turf grasses. The more dense the turf, the more difficult it is for the young seedlings of other plants to become established. Any cultural practices, therefore, which encourage the vigorous growth of grass will simultaneously discourage the weeds.

Fertilizers and Lime Encourage Grasses

Over a period of years the United States Golf Association Green Section, in cooperation with the Bureau of Plant Industry of the United States Department of Agriculture, has been conducting experiments planned to determine the response of turf grasses to various fertilizers and combinations of fertilizers. The plots of

FIG. 1

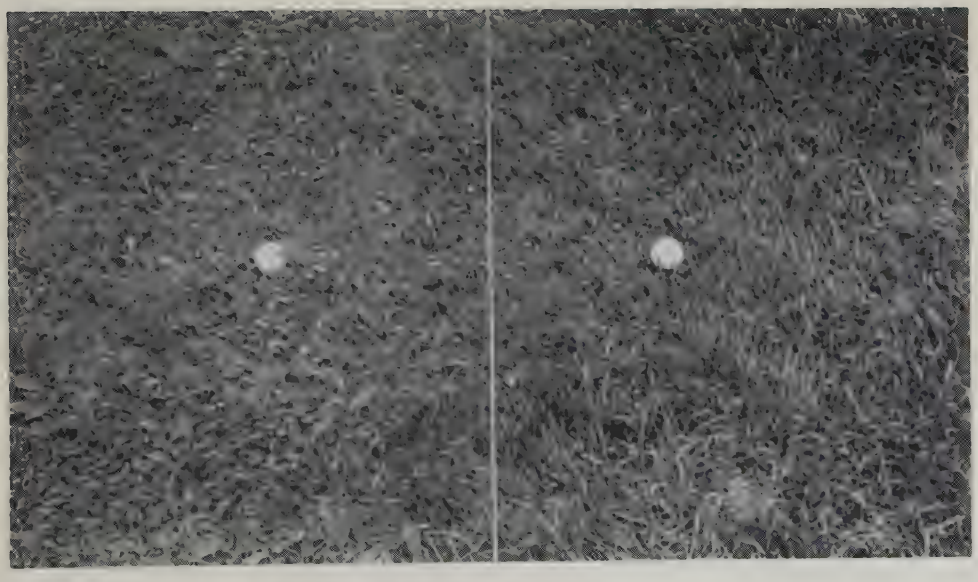


FIG. 2

FIG. 1.—Nine samples of compost which were being used for top-dressing in various places showed remarkable differences in weed infestation when placed in flats and exposed to growing conditions. Tests of this kind have demonstrated that it is not unusual to sow 70,000 weed seeds on a putting green in a single top-dressing.

FIG. 2.—Reduction of weeds and increase in density of an established Kentucky bluegrass turf by the use of fertilizer. Note the abundance of buckhorn plantain and clover in the unfertilized plot on the left as compared with the dense, weed-free Kentucky bluegrass turf on the fertilized plot on the right.

Kentucky bluegrass have not been hand-weeded and the plant populations on these plots have been recorded each year in June and again in October. Results from these plots, therefore, not only indicate the effect of the various fertilizers on Kentucky bluegrass, but likewise their secondary effect on the weed population. In all the fertilizer trials where moderate rates of application were used, inorganic fertilizers have been much more effective than the organic fertilizers in reducing the percentage of weeds. At heavier rates of application the results have been more nearly equal.

Typical results were obtained from an experiment established on an old lawn at the Arlington Experiment Farm of the U.S. Department of Agriculture in April, 1934. The acid soil on this lawn was an infertile silt loam. Nitrogen was applied in the form of sulfate of ammonia alone on some plots, in combination with phosphorus (as superphosphate) on others, with potash (as muriate of potash) on others, and with both on still other plots. The value of lime was tested by combining it with nitrogen alone, with nitrogen and phosphorus, with nitrogen and potassium, and with nitrogen, phosphorus and potassium combination. The nitrogen and phosphate were applied in spring and fall at the rate of 108 lb. per acre each season, potash at the rate of 49 lb. per acre, and lime at the rate of 1,000 lb. per acre.

Without exception, through each of the five years in which the experiment has been in progress, the greatest improvement in the turf over that on the unfertilized check plots was shown on those plots which received nitrogen and phosphorus in combination with lime. Taken over the period of five years, the presence of potash did not significantly affect the improvement resulting from the other three ingredients. In October, 1939, improvement in the grass with each of these two fertilizer combinations, nitrogen-phosphorus-lime, and nitrogen-phosphorus-potash-lime, was approximately 337 per cent. An example of some of these results is shown in the accompanying table. This excellent improvement in turf has been accompanied by a good control of crabgrass and plantain.

Weed infestation of turf as affected by applications of Nitrogen (N), Nitrogen-Potash (NK), Nitrogen-Phosphorus (NP), Nitrogen-Phosphorus-Potash (NPK), and these combinations plus Lime (L). Results are expressed in percentage improvement in grass and percentage change in weed population. A plus sign indicates an increase and a minus sign a reduction.

	Nitrogen		Nitrogen Potash		Nitrogen Phosphorus		Nitrogen Phosphorus Potash	
	N	NL	NK	NKL	NP	NPL	NPK	NPKL
Percentage improvement, grass ..	+90	—7	+33	+57	+367	+343	+67	+330
Percentage change in crabgrass population	+156	—62	+192	+52	+10	—96	+160	—92
Percentage change in plantain population	—99	—85	—96	—85	—99	—97	—96	—99
Percentage change in clover population	—99	+101	—99	—9	—99	—4	—99	—4

An example of the effect of lime on the response of the turf to fertilizers on these plots during the last five years is shown in this table. For each fertilizer, the percentage improvement in the fall of 1939 and the percentage control for each of the weeds which were prevalent in this turf at that time are given. The results with the fertilizer alone are given in one column and those obtained by the application of lime in addition to the fertilizer in the adjacent column.

It will be seen in this table that the addition of lime to the fertilizer elements with but two exceptions resulted in a greater improvement in turf and in a reduced stand of crabgrass for each combination of fertilizer elements. At the same time the use of lime resulted in a diminished control of plantain and clover. This was to be expected, particularly in the case of clover, since lime has long been used to encourage it in pastures.

Mowing Height and Frequency

It is difficult to establish or maintain an area of a desirable kind of plant without undesirable ones invading the area. The frequent mowing of turf naturally eliminates many tall-growing weeds which are troublesome in agricultural fields. However, other grasses and some rosette- and mat-forming plants are about as well adapted to a closely clipped environment as are the turf grasses. These plants usually become serious weeds in turf, especially if the grass is not kept in a vigorous condition.

Kentucky bluegrass is seriously reduced in vigor if mowed too closely. The close mowing causes a reduction in root and stolon production and results in a weakened open turf, as was reported by Harrison in the Bulletin of the United States Golf Association Green Section for 1931. This loss in vigor favors the encroachment of many turf weeds. A slightly higher cut allows a much more vigorous growth of bluegrass which competes more successfully with the weeds.

Bluegrass grows remarkably well when mowed at 1.25 to 1.5 inches. Cutting the turf at 0.5 to 0.75 inch greatly reduces the vigor of the bluegrass and favors the growth of weeds. On certain sports fields the demand for a closely clipped turf results in a thin stand of grass which is readily invaded by weeds.

Fescue (*Festuca* spp.) will stand closer mowing than will Kentucky bluegrass, but in U.S.A. fescue is frequently badly damaged by diseases, with the result that weeds may easily dominate it.

Bent grass, especially creeping bent (*Agrostis palustris* Huds.) and velvet bent (*A. canina* L.) can be successfully maintained at a much lower height of cut. Other conditions being favourable, bent grass will thrive when cut as close as 3/16th of an inch. At this low cut there is less danger from diseases which frequently kill out areas and permit the invasion of certain weeds. Grasses used for turf in the southern section of the country are much less sensitive to the height of cut.

The turf on many lawns and parks is injured as much by infrequent irregular mowing as by the low cut. This type of mowing is very damaging on nearly all types of grass turf, yet it is the common practice on many lawns and parks. The resulting weakened condition of the grass allows the invasion of numerous weeds.

Hand Weeding

Unfortunately other plants thrive under the cultural practices which are considered best for turf grasses. Such plants become troublesome weeds and must be controlled by methods other than the cultural methods referred to above. Therefore, in addition to the accepted fertilizer and mowing practices which result in improved turf and decreased weed population, hand-weeding has been adopted for the control of weeds in lawns, putting greens and other turfed areas. Many weeds such as crabgrass and plantain can be removed by hand successfully without too greatly disturbing the surrounding grass. The mat-forming weeds, such as clover, however, with their networks of rhizomes or stolons running through the turf, are extremely difficult to remove by hand. In areas where the turf is heavily infested with weeds, hand-weeding frequently results in serious injury to the turf grasses.

On limited areas with only a scattering of weeds, hand-weeding is probably still the most satisfactory method of maintaining a weed-free turf. With rising costs of labor, however, and increasing demands in this country for weed-free turf on large areas, hand-weeding in many cases is no longer practical. This is particularly true on areas which are heavily infested with weeds and on turf in which the predominant weeds are of a mat-forming type.

Chemical Control of Weeds

Because of the shortcomings of hand-weeding in the light of present-day demands for turf, numerous investigators have directed their attention to the control of weeds by the application of chemicals. This method of weed control involves the well-recognized principle that some plants are more susceptible to chemical injury than others. According to this principle, in a mixed stand of plants it is possible to destroy one group of plants without permanently injuring another group. The methods of application are relatively simple and many of the chemicals are not expensive.

Chemical weed control work in this country was initiated by the investigations of Professor Bolley in North Dakota in 1896. He was concerned primarily with the control of weeds in the western grain fields. He found that certain of these weeds, particularly mustard, could be controlled without serious injury to the grain by spraying the fields with a solution of sulfate of iron.

Herbicides Used on Agricultural Lands

Investigations on the chemical control of weeds in our cultivated fields have been pursued by many investigators in various sections of this country and Canada. Compounds differing widely in their chemical properties and physiological effects have been studied.

The table below lists alphabetically some of the chemicals that have been tested for weed control in this country.

I. **Arsenicals**: arsenic acid, arsenic pentoxide, arsenic trioxide, sodium arsenate and sodium arsenite.

II. **Chlorates**: calcium chlorate, sodium chlorate and zinc chlorate.

III. **Cyanides and Related Compounds**: including ammonium thiocyanate; calcium cyanamide; hydrocyanic acid; potassium compounds as cyanate, cyanide, ferrocyanide, ferricyanide and sulfocyanide; and sodium compounds as cyanide and sulfocyanide.

IV. **Miscellaneous Inorganic Compounds**: including borates, borax, boric acid; carbonates; chlorides of sodium and zinc; chromates and dichromates; copper phosphate; nitrates of sodium and copper; oxides and hydroxides; and selenium compounds.

V. **Organic Compounds**: acetic acid, asphalt emulsions, benzene, chloropicrin, creosotes, cresols, crude oil, Diesel oils, formaldehyde, fuel oils, gasoline, kerosene, petroleum, phenols, tar emulsions, and various unsaturated oils and fats such as mercurated-ethyl-stearate.

VI. **Sulfur Compounds**: including barium sulfide; carbon bisulfide; kainit; sodium bisulfate; sodium bisulfite; sulfates of ammonium, copper, iron (ferrous), magnesium, silver and zinc; and sulfuric acid.

Many of these appeared to offer some promise for the control of turf weeds and their possibilities for this purpose have been studied.

Herbicides for Turf Weeds

For years, therefore, the Green Section has been trying various types of herbicides on the weeds prevalent in Kentucky bluegrass lawns as well as in stands of bents and fescues. In the work prior to 1933 some of the best results were obtained with sodium chlorate. Crabgrass was best controlled by three successive applications at the rate of 2 lb. per 1,000 square feet, applied dry mixed with sand. With this treatment practically all other common turf weeds such as plantains, field or sheep sorrel (*Rumex acetosella* L.), chickweeds, milk purslane (*Euphorbia maculata* L.), ground ivy (*Nepeta hederacea* Trev.), self-heal and speedwell disappeared within a single season. Dandelion and goosegrass were discouraged whereas garlic was little affected. Sodium chlorate always presents a fire hazard when used in solution. In this work, therefore, it was applied dry, thereby virtually eliminating the danger of fire. When applied in the dry form, the chemical is mixed with an amount of dry sand, fertilizer or compost which can be easily spread over a given area. This mixture may be broadcast by hand or distributed in a lime or fertilizer spreader.

In addition to the use of sulfate of ammonia as a fertilizer, its burning effect when used in concentrated quantities is made use of to control weeds. Small areas and mild infestations of many turf weeds are controlled by repeatedly scorching the leaves with sulfate of ammonia. Calcium cyanamide is used in a similar manner, but to a less extent.

Excellent results were also obtained by the use of various compounds of arsenic on lawn, fairway and putting green turf. Satisfactory selective control of clover, pennywort, ground ivy, *Galium* sp., knotweed (*Polygonum aviculare* L.), chickweeds and self-heal was achieved. Arsenic compounds can be applied equally as easily and safely in solution as mixed with sand. Since in the United States livestock rarely have access to grass used for turf purposes, poisons such as arsenicals which cannot be used on pastures may be safely used on these areas.

For large scale applications it is frequently a great deal more economical to apply the chemical in solution than to distribute it in sand. This is particularly true on parks and golf courses where power sprayers are used for other purposes and are therefore available for use without any additional cost. These power sprayers are equipped with a large boom arrangement 12 to 20 feet long, with the spray nozzles about 18 inches apart and 18 inches above the ground. The solution is applied as a spray of fine mist at high pressures. With this equipment large acreages can be covered in a relatively short period of time.

Because of the freedom from fire hazard and other advantages which the arsenicals offer over sodium chlorate, the Green Section has used various compounds of arsenic in experiments in recent years at the Arlington Experiment Farm. Many other herbicides have been and are being tried each season. However, the best results to date have been obtained with arsenic acid and sodium arsenite. Nearly equal results have been secured with the anhydrous arsenic acid (As_2O_5) and the crude liquid arsenic acid (70 per cent H_3AsO_4. 0.5 H_2O) when compared on the basis of arsenic content. In the United States crude liquid arsenic acid is the cheaper product and is therefore generally used.

Time and Rate of Application of Arsenicals

The time and rate of application of any herbicide depend on the method of application, the kind of grass in the turf and the specific weed to be controlled, as well as on the climatic conditions prevailing in that section of the country where the work is to be conducted. It is not possible, therefore, to make a definite recommendation covering rates of application to suit all conditions.

Generally speaking, the arsenicals are more efficient when applied in spray than when applied dry, mixed with sand. At the same time, the injury caused to the turf grass will be greater when the compound is sprayed on than when the same compound is applied at the same rate in sand. Only one half to one-third as much material is required when the arsenical is to be used in a spray as would be necessary if the same chemical were to be applied dry.

The turf grasses vary in their resistance to injury from the arsenicals. Kentucky bluegrass and Bermuda grass are most resistant. They may be temporarily browned by the treatment, but recovery is usually prompt and complete. The resistance of some of our other common turf grasses decreases in the following order :—the fescues, the bents and *Poa trivialis*. The rate of application as used on Kentucky bluegrass turf must be reduced if the turf in question is composed of some of the more sensitive grasses.

The height of the grass at the time of treatment also influences the amount of injury which will result from the treatment. The shorter the grass, the greater is the injury which results,

Just as the grasses vary in their resistance to injury from the arsenicals, so the weeds differ in their resistance to injury. This variation in the resistance of weeds to herbicides may be due to differences in size, shape and structure of the leaves, to kind and distribution of roots and to growth and seeding habits.

Annual weeds and the mat-forming types such as the chickweeds are generally more susceptible to arsenical poisoning than are deep-rooted perennials such as dandelions. A single application of sodium arsenite or arsenic acid at the rate of 3 or 4 ounces to 1,000 square feet is often sufficient to control an infestation of mat-weeds. Eradication is more difficult, however, in the case of the perennials such as the dandelions and plantains. This may be associated with the fact that sufficient reserve food is stored in the large roots to enable them to send up new shoots even though the old tops are burned to the crowns. For such weeds, treatments at approximately two to three week intervals, depending on the amount of recovery the plants have made, are frequently successful.

Comparison of effectiveness of one application of sodium arsenite at various rates on different weeds. Treatments made in March. Observations on control made in April and June.

Weed	Percentage of control of weeds		
	Sodium arsenite 0.25 pound in spray	Sodium arsenite 0.375 pound in sand	Sodium arsenite 0.75 pound in sand
Plantain	30	14	25
Chickweed	100	100	100
Clover	60	67	84

An example of the effect of the arsenicals on different weeds is shown in this table. These results are taken from one application made in March and therefore show the effect only on weeds which were present at that time. Generally speaking sodium arsenite is slightly more toxic than arsenic acid applied at the same rate. It also causes a greater burn on the grass foliage.

The time of year at which arsenical treatments will be most successful depends in a large measure on the growing and seeding habits of the weeds to be eradicated. Some weeds, such as chickweed, which make their best growth in late fall and early spring, are best controlled by early spring applications. In order to cause the minimum amount of injury to the grass, these applications should be so timed as to permit the turf grasses to recover before hot weather starts.

On the other hand, there are annuals such as crabgrass which germinate from early to late summer and make their best growth in midsummer. Although these annuals are most easily killed with arsenicals by applications made in the seedling stage, such applications are seldom practical. Turf grasses are temporarily severely injured by applications of arsenicals during the hot summer months, and this injury

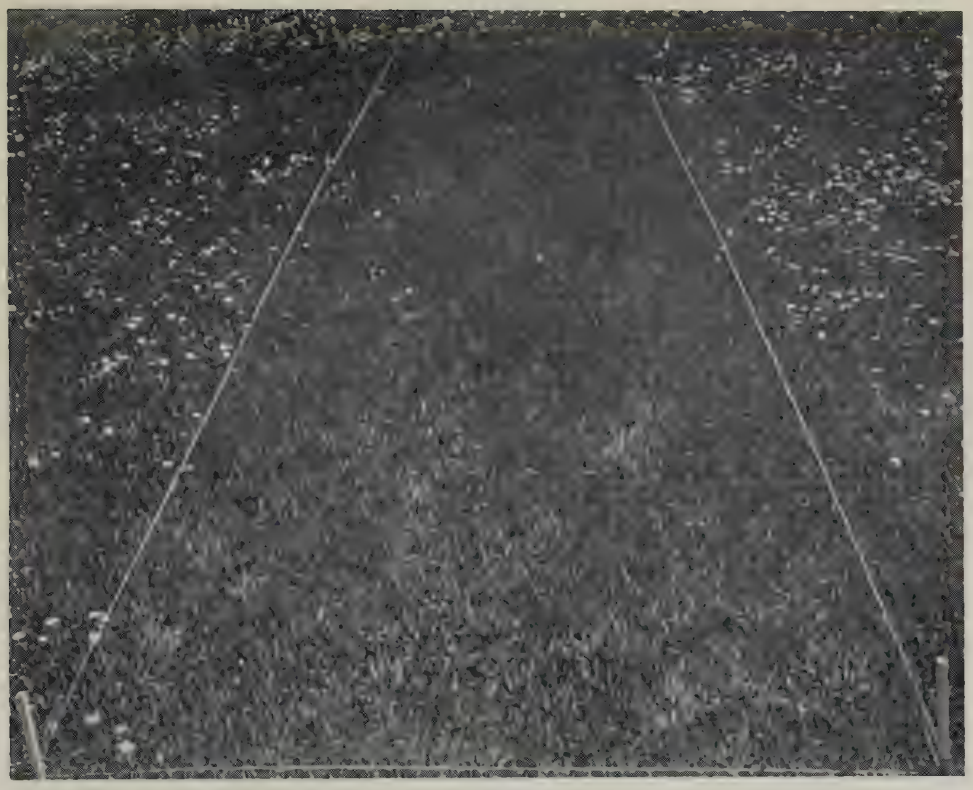


FIG. 3.

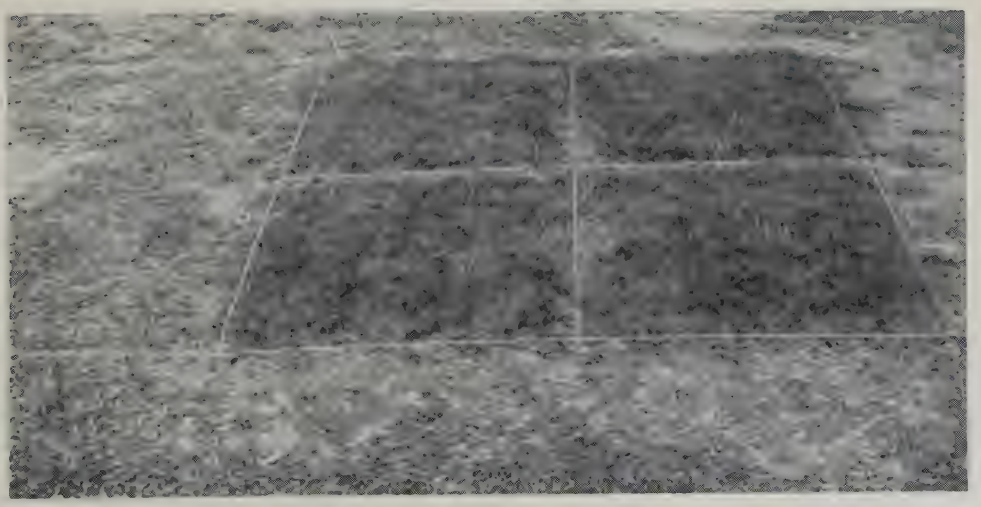


FIG. 4.

FIG. 3.—Control of dandelions with arsenicals. The outlined strip of Kentucky bluegrass turf has been treated with arsenicals. The strip is surrounded by untreated areas showing dandelions in flower. Neither seed nor fertilizer was used on the treated area.

FIG. 4.—Establishing new grass on old weedy turf with the aid of chloropicrin. The five plots shown were seeded at the same time. The dark-colored plots of vigorously growing grass at the right had been treated previously with chloropicrin. Competition from weeds prevented the grass from becoming established in the plot at the left. The surrounding area shows the poor weedy condition of the turf.

permits succeeding infestations of crabgrass to become established before the grass recovers. These annuals therefore are most effectively eradicated from turf by treatments in late summer before the seeds mature and after germination has ceased.

If a heavy growth of crabgrass has been present in bluegrass turf under favorable conditions, it may have smothered much of the bluegrass by the end of the summer. After killing the crabgrass in such cases, therefore, fertilizer should be applied to encourage the bluegrass which remains. The bare areas should be reseeded in order that they may be covered before the chickweed or winter annuals appear in the late fall. The fertilizer and seed may be distributed at the time of the application of the arsenical or immediately afterwards, since the arsenic will then have no effect on the seed or the young seedlings.

Where repeated applications are necessary to control perennial weeds, the seeding should be in combination with the last arsenical treatment, since seedlings of the turf grasses are severely injured by applications of arsenicals. This combination of treatments makes it possible for the bluegrass to become established in a dense stand with the minimum amount of competition from weeds. The months of September and October offer growing conditions which are ideal for Kentucky bluegrass.

In the district around Washington, D.C., the results of numerous treatments on weedy Kentucky bluegrass turf have demonstrated that generally a satisfactory control of weeds can be achieved by application of sodium arsenite or arsenic acid as a spray in early September at the rate of 4 ounces to 1,000 square feet. Applications result in the least injury to the grass and the best control of weeds when made on clear days when the temperature is not too high, the foliage of the turf dry, and the soil moisture favorable. Should rain fall within 24 hours after treatment, the applications may have to be repeated after a week or more if the weeds have not been killed.

If a good kill of the weeds does not result the application may be repeated at intervals of two weeks until a satisfactory control is achieved. This is better than to increase the rate, which would mean an increase in the injury to the grass. If the arsenicals are applied in sand instead of a spray, a higher rate will have to be used—perhaps as much as 0.5 to 1 pound per 1,000 square feet. If the turf consists largely of bents or fescues instead of Kentucky bluegrass, the rate may have to be reduced because of the greater sensitiveness of these grasses to arsenical poisoning.

Killing Weed Seeds in Soils with Chemicals

In areas which have been badly infested with weeds for several years it is frequently desirable to destroy the weed seeds as well as the plants before seeding or reseeding to grass. Various methods have been used for this purpose, such as fallowing the ground for at least one season, or partially sterilizing the soil with drastic doses of some of the herbicides such as the chlorates.

On turfed areas, however, it is desirable to kill the seed in the soil as well as the weeds without fallowing. With badly infested turf the practice has been to skin off the sod. Unfortunately, this practice not only removes some of the best topsoil, but also brings to the surface weed seeds which have been distributed at too great depths in the soil to permit of germination.

By the use of chloropicrin (trichloronitromethane, CCl_3NO_2), it is possible in one treatment to kill the ungerminated weed seed in the soil as well as all vegetation. In this way all plants, weeds and grass alike, are killed and yet the topsoil is left undisturbed. Moreover, the area can be seeded to grass within a week or 10 days following treatment, and the resulting stand of grass has in many cases shown the effect of a decided stimulation due to the treatment with the chloropicrin. Since this is at present an expensive treatment, however, it is therefore practicable only on limited areas.

Method of Application

In applying chloropicrin to soils for the purpose of sterilization, it must be introduced into the soil at the depth to which sterilization is desired. Since it is extremely volatile, the soil must be covered at once to prevent its escape before it has had time to kill the vegetation and seeds.

Apparently the simplest and most satisfactory method of application at present is to inject the chloropicrin in measured amounts into the soil to a depth of 2 to 3 inches in furrows 6 to 8 inches apart, depending upon the nature of the soil. The furrows are closed immediately and the entire treated area is covered with a gas-proof paper, the edges of which are sealed by placing them in shallow trenches and covering with soil. After four days the cover is removed and any gas remaining in the soil is allowed to escape. Within a week or ten days after treatment the soil can safely be seeded with grass.

Time and Rates of Application

Experiments conducted on both Kentucky bluegrass and Bermuda grass turf have shown that all vegetation, even the tough, resistant rhizomes of Bermuda grass and the bulbs of garlic (*Allium vineale* L.), are killed at rates as low as 14 lb. per 1,000 square feet. This rate has also killed about 90 per cent of all weed seed present in the soil. Grass seed sown a week after treatment has resulted in decidedly better stands on the treated plots than on the untreated plots.

The effectiveness of the chloropicrin is influenced by the moisture and temperature of the soil at the time of application. Weed seeds have been killed more efficiently in a medium-wet than in either an extremely dry or extremely wet soil. The higher the temperature the greater has been the percentage of weed seeds killed. These facts probably explain why, in the field experiments at Arlington Farm, chloropicrin has been more effective in midsummer than in spring or fall. In June and July, 98 per cent of the weed seeds were killed by treatments which resulted in only 76 per cent kill when repeated at the same rate in late September and October.

Susceptibility of Seeds of Different Weeds

The seeds of our various common weeds differ in their susceptibility to chloropicrin. Seeds of such weeds as chickweed, witchgrass (*Panicum capillare* L.), quackgrass (*Agropyron repens* (L.) Beauv.) and nutgrass are easily killed, whereas clover seed is relatively resistant. The percentage of crabgrass seed killed has not been so high as in the first four weeds mentioned. The seed of plantain, *Poa annua*, foxtail (*Setaria* spp.) and *Muhlenbergia* spp. are killed relatively easily.

Sterilization of Compost

Some types of high-quality turf are frequently top-dressed with compost. This top-dressing often brings in weed seed and any weed control program must recognize this source. Much of the soil used for compost in the past was a fertile source of weed seed, as it was customary to use any odd lot of soil. Usually this soil was heavily infested with weed seeds. In present practice, an effort is made to obtain soil from woods or areas where turf weeds are not likely to be present. Where compost piles are used, it is possible to destroy most weed seeds by the proper handling of the pile. However, such handling involves considerable labor and in practice poor results are often obtained. Because of this failure the use of steam or dry heat partially to sterilize the soil is coming into more general use.

Recent developments with chloropicrin have indicated that this chemical is useful for the purpose, especially where equipment for sterilizing soil by steam or dry heat is not available. This method leaves the soil in much better condition than does the steam method.

An example of the excellent results which have been obtained is shown by an experiment in which 5 cubic yards of compost were treated with chloropicrin at the rate of 30 ounces (by weight) to the cubic yard. A pro-rated quantity of chloropicrin was sprinkled over each 6-inch layer of the compost as the pile was built up. The pile was then sealed with gas-proof paper immediately and left covered for four days. Flats of compost were taken before and after the treatment and placed under conditions favorable for growth. The results have shown that 100 per cent of the seeds of crabgrass, chickweed and *Poa annua*, 40 per cent of goosegrass and 15 per cent of clover were killed. No toxic effects remained, for redtop grew vigorously when seeded in this soil.

B. Rademacher Germany

THE CONTROL OF WEEDS IN GERMANY*

A. THE IMPORTANCE OF THE WEED QUESTION IN GERMANY

In spite of continuous efforts for the control of weeds, they are still the source of heavy losses in Germany. Naturally these vary much from year to year, and it is difficult to make any exact estimate of their extent. On the basis of various calculations, the figure representing the losses incurred on account of weeds has been estimated as from 0.9 to 1.2 milliard Reichsmarks yearly for the whole area of greater Germany.

Even if it is impossible entirely to eliminate these considerable losses, their reduction offers to-day one of the most promising prospects of further increasing crop yields in Germany. Those regions of the country which show the highest yields are at the same time those also in which the eradication of weeds is most intensive and therewith the freedom from weeds greatest. Before the year 1914 this freedom from weeds was most noteworthy in the central German black earth region, which from time immemorial had been in uninterrupted use as arable land. In some parts of this region premiums were paid for every single plant of *Sinapis arvensis* which was still found after the spring weeding. A great deterioration took place in this land as a result of the world war, but loss from weed growth has once more been practically eliminated. The poor and the high-lying lands which constitute a great part of the agricultural area of Germany still show in places a heavy overgrowth of weeds. Their elimination for the further increase of yield per unit area is—with the dense population of Germany, 136.4 people per square kilometre—an urgent necessity.

The following article presents a brief outline of the steps taken to-day for the control of weeds, especial emphasis being placed upon those processes which are of more recent date and play a special part. These include also chemical means of control, which have been considerably developed during the last two decades.

In referring to the literature I shall confine myself to more recent work. For comprehensive work on weeds and weed control under conditions in Germany reference is made to that by Wehsarg (**45, 46**), Braun (**3**), Meyer-Hermann (**28**), and Eichinger (**8, 9**). The classic work of Emil Korsmo, "Unkräuter im Ackerbau der Neuzeit" [Weeds of modern arable land] (**20**), available in the German translation by H. W. Wollenweber, is to a considerable extent valid also for German conditions, although a number of species important in western, southern and south-eastern Germany are lacking therein. Much valuable information on the weeds of grassland is contained in the special grassland literature by authors such as Klapp (**17**), Petersen, Knoll, Weber and others.

*Manuscript received August, 1939; translation from German made by G. M. Roseveare.

In Germany, research on weed growth is conducted partly by agricultural research stations and partly by phytopathological and botanical research institutes. Among present-day workers O. Wehsarg occupies a prominent position for his monographs on many individual weed species, his many years' study of the root-propagated weeds, and his comprehensive publications. H. Braun is working on problems of weed control at the Biologische Reichsanstalt, Berlin-Dahlem, and has made a name for himself by his articles and the book referred to above. To K. Meyer-Hermann are owing numerous articles on the control of weeds, especially in the early stages of growth, by means of fertilizers and chemicals.

A. Eichinger has made a detailed study of the importance of the weed flora for the estimation of soil quality and of its calcium content in particular. A. Petersen makes use of the weeds in judging the value of grassland and arable land. F. Fürst and J. Weigert have paid special attention to problems of weed control in the south of Germany, and H. L. Werneck to the same problems in the Danube region. B. Rademacher is making a special study of the mutual effects of weeds and crop plants upon one another. All German grassland workers are occupied with the suppression of weeds in meadows and pastures. Mention should also be made of the thorough work of Buchli in Switzerland, which, in addition to general information, has much matter of importance for conditions in south-western Germany.

The study of weed sociology is still in its initial stages. In addition to individual articles by Eichinger, Hanf (**15**) and others, floristic studies of different regions also take the weed associations into consideration. This is true, for example, of work by Tüxen (**43**), Kuhn (**22**), Knoll (**19**), and others, among whom special mention must again be made of the grassland workers, Klapp and Staehlin (**18** etc.).

Articles on the subject of weed research are somewhat scattered among agricultural and phytopathological periodicals and those concerned with applied botany. The "*Zeitschrift für Pflanzenkrankheiten*" has presented abstracts of the more important work in this field from 1937 onwards.

B. THE MOST IMPORTANT WEEDS IN GERMANY

The following review deals only with those weeds which are found to be dangerous or noteworthy throughout the whole Reich, or at all events throughout the greater part of it. By the term "weed" we denote those plants which are undesirable in cultivated land and a source of injury to crop plants. Under certain circumstances, therefore, crop plants may represent weeds, and indeed it is not possible to make an entirely clear distinction between crop plant and weed. This is especially true in the case of grassland plants. In grassland the same plant may represent, according to circumstances, sometimes a crop plant and at other times a weed ("facultative weeds.")

In the following review, weeds have been arranged in accordance with their preponderance in arable land, horticultural land, gardens, orchards, vineyards, or grassland respectively.

1. Weeds of arable land

In this group weeds characteristic of the different crops may be distinguished,

although many species are not strictly confined to definite crops or are preponderantly found, according to year and locality, now in one crop, now in another. The classification of weeds of arable land in accordance with the different crops is made, therefore, with certain reservations.

(a) Weeds of cereal crops

Stellaria media L. Weed of winter-sown cereals, especially of winter barley, with the increasing cultivation of which it is becoming more widely distributed (Rademacher 34). Improvement in the supply of humus and in manurial practice is encouraging its still wider distribution. The damage done by this plant consists principally in the uptake of nitrogen and in the suppression of the cereal crop. It is a source of damage also to many other crops.

Veronica spp. The most frequent and most injurious species is *V. hederifolia* L., which is becoming increasingly widely distributed as a weed in wheat on better-class soils and can be a source of very great injury through the removal of nitrogen (Weigert and Weizel 49). On lighter soils it is superseded by *V. triphyllos* L. The other *Veronica* spp. also are associates of winter-sown crops.

Lamium spp. Together with *Stellaria media* and the *Veronica* spp., *Lamium purpureum* L. and *L. amplexicaule* L. are constant associates of winter cereals, especially barley and wheat. As in the case of *Stellaria* and *Veronica*, their main growth takes place in the period between late autumn and spring. They start seeding as early as April. *L. amplexicaule* prefers soils well supplied with lime.

Capsella bursa-pastoris Moench. is found mainly in winter-sown cereals, particularly in barley on better-class soils.

Stenophragma Thalianum Cel. replaces *Capsella bursa-pastoris* in winter cereals on poorly manured and sandy soils. It is less injurious than the former.

Centaurea cyanus L. is a dangerous and widely distributed weed of winter cereals, especially of rye.

Papaver spp. are also among the most dangerous weeds of winter cereals, especially of wheat. *Papaver Rhoeas* L. prefers good soils not deficient in lime, *P. argemone* L. the poorer soils with a higher proportion of sand. *P. dubium* L. takes an intermediate position.

Delphinium consolida L. is distributed sporadically only, where it finds soils with an adequate lime content. In such places this plant is a troublesome winter weed.

Agrostis spica-venti L. is one of the most dangerous weeds of arable land. The species is found principally in winter cereals, and favours poorly drained, loamy to sandy loam soils.

Alopecurus agrestis L. is less common than *Agrostis spica-venti*, but no less dangerous. It is a weed of winter cereals, barley and wheat in particular, but is also found in summer cereals and clover on better soils not deficient in lime.

Bromus secalinus L. This weed of winter rye has been practically eradicated from Germany through good seed cleaning.

Anthoxanthum aristatum Boiss. A troublesome weed of winter rye, its area of distribution being limited to north-west Germany.

Agrostemma githago L. has become rare at the present time in consequence of good seed cleaning, and is only found to any noteworthy extent in neglected areas.

Galium aparine L. A weed of winter cereals, but also found in summer cereals on better soils not deficient in lime. It is especially feared, because its presence in large quantities leads to lodging.

Ranunculus arvensis L. A weed of winter and summer cereals in loamy fields not deficient in lime.

Lithospermum arvense L. On account of its poor capacity for reproduction, this weed of cereal crops is not very dangerous.

Allium vineale L., only in some places a frequent and troublesome weed of cereals and of other crops.

Vicia spp. Dangerous weeds of winter and summer-sown cereals. The species most frequently encountered are *Vicia hirsuta* Koch, *V. tetrasperma* Mnch., and *V. angustifolia* Alt.

Matricaria and *Anthemis* spp. *M. chamomilla* L. and *M. indora* L. are dangerous weeds of cereals, as is the related *Anthemis arvensis* L.

Anchusa arvensis Bieb. A generally distributed weed which, however, does not usually occur in large quantities ; injurious as an intermediate host of *Puccinia dispersa.*

Sinapis arvensis L. and *Raphanus raphanistrum* L. are the most widely distributed and dangerous seed-propagated weeds of summer cereals and, more rarely, of winter cereals also. *Sinapis arvensis* is more frequently found on better soils not deficient in lime, *Raphanus raphanistrum* L. more frequently on poorer and acid soils.

Thlaspi arvense L. is a widely distributed and troublesome weed of summer and winter cereals.

Galeopsis spp. are, when they occur in masses, very dangerous weeds of summer and winter cereals. *G. tetrahit* L. and *G. ladanum* L. are more commonly distributed ; *G. speciosa* Mill. is found principally in moorland and hill country.

Chrysanthemum segetum L. is a very irregularly distributed weed of summer cereals, apparently more frequent formerly.

Spergula arvensis L. A weed of cereals and of other crops where there is incipient or advanced soil acidity.

Polygonum spp. The most common and dangerous species in cereals is *P. convolvulus* L. Other species also are found in moorland.

Avena fatua L. A dangerous weed of summer cereals in the better soils.

Lolium temulentum L. A weed of summer cereals. Its distribution has become greatly reduced.

Semi-parasites. In cereals the two principal species are *Melampyrum arvense* L., which grows mainly in lime soils, and *Alectorolophus hirsutus* All., found principally in the south of Germany (Fürst 11).

(b) Weeds of root crops

Polygonum spp., especially *P. persicaria* L. and *P. lapathifolium* Auct., are dangerous weeds of all late root crops.

Chenopodium album L. A dangerous and widespread weed in all land that is not acid (Schmalfuss 37).

Atriplex spp. Certain species are troublesome in some places.

Solanum nigrum L. is a widely distributed weed of sugar beet fields in particular. It is found especially in nests attacked by *Heterodera schachtii* Schm.

Galinsoga parviflora Cav. In places a very undesirable weed.

Amarantus spp. *A. retroflexus* L. and *A. Blitus* L. are troublesome weeds in some places, especially in the southern part of the Reich.

Mercurialis annua L. A dangerous weed, especially in central and western Germany, growing late in the year.

Sonchus spp. The species *S. oleraceus* L., *S. asper* All., and *S. arvensis* L. are dangerous weeds of root and other crops.

Senecio vulgaris L. A universal weed, with a preference for late root crops.

Setaria spp. The late-flowering species occur as weeds of root crops in particular. With the exception of *Panicum Crus-galli* L., they prefer definitely acid soil.

Fumaria officinalis L., a widespread weed of root and other crops on neutral soils.

(c) Weeds of clover and lucerne

Plantago lanceolata L. is a dangerous competitor for space in all insufficiently close clover and lucerne fields.

Poa annua L. initiates the dreaded " grassing " of lucerne fields, together with other weed grasses such as *Agrostis alba stolonifera* E. Mey., *Holcus lanatus* L. and *Bromus* spp.

Senecio vernalis W. et K., a dangerous weed of lucerne from the south-east, has spread during the last decades to the west and south of Germany.

Capsella bursa-pastoris L. is a constant associate of clover and lucerne.

Geranium spp. (*G. molle* L., *G. dissectum* L. and others), together with *Erodium cicutarium* L'Hérit., are also troublesome weeds.

Parasites. Of the parasites, *Cuscuta* spp., (*C. epithymum trifolii* L. and *C. racemosa* Mart.) have become rare on account of good seed cleaning, and are only found with any frequency in Upper and Lower Austria. Of the *Orobanche* spp., *O. minor* Sutt. is a dangerous weed of clover fields, especially in western Germany.

(d) Weeds of various field crops

Scleranthus annuus L. is the most well-known indicator of acid soils (Steyer and Eberle 42), but is not dangerous as a weed. *Spergula arvensis* L. also, which has already been mentioned, is found in the greatest variety of crops.

Rumex acetosella L. is a troublesome root-propagated weed of acid land.

Rumex crispus L., a generally distributed root-propagated weed.

Convolvulus arvensis L., a dangerous weed of cereal and root crops.

Cirsium arvense Scop. Except in the poorest types of soil, this species is common and is among the most dangerous of weeds.

Sonchus arvensis L. occurs in widely different soil types in cereal and root crops.

Tussilago farfara L. is one of the most dangerous usurpers of space. It is often found in masses, especially where there is a wet subsoil not deficient in lime.

Equisetum arvense L. is also one of the most troublesome weeds of field crops in nearly all kinds of soil, especially those which have a wet subsoil.

Stachys palustris L. A dreaded weed of wet soils, especially in the north of Germany.

Lepidium draba L. A newly introduced, dangerous root-propagated weed of many crops.

Agrostis alba stolonifera E. Mey. A common weed grass with great ecological range of distribution and multiplicity of forms.

Holcus lanatus L. is widespread in all poor and ill-kept land.

Holcus mollis L. A troublesome weed of all very acid land.

Triticum repens L. A widespread and very dangerous weed.

2. Weeds of horticultural land

The weeds found in horticultural fields take an intermediate place between those found in arable and garden land respectively. They are nearly all plants encouraged by manuring and having rapid seed production, capacity for rooting again quickly, and the ability to ripen seed even after the plant has been cut down. The following are the principal species of importance :

Urtica urens L., *Mercurialis annua* L. (rare in northern and eastern Germany), *Euphorbia helioscopia* L., *Stellaria media* Cyr., *Veronica hederifolia* L., *Senecio vulgaris* L., *Lamium purpureum* L. and *L. amplexicaule* L., *Erigeron canadensis* L., *Capsella bursa-pastoris* L., *Thlaspi arvense* L., *Poa annua* L., sometimes also *Chenopodium album* L., and *Solanum nigrum* L.

3. Weeds of gardens

The same species as noted for horticultural fields are found in gardens, and, in addition, *Atriplex hortense* L., *Sonchus asper* All. and *S. oleraceus* L., and *Euphorbia peplus* L.

4. Weeds of orchards and vineyards

In forest nurseries the same weeds are troublesome as in horticultural fields ; in orchards *Anthriscus silvestris* L. Hffm. is especially frequent, and where there is much shade *Aegopodium podagraria* L., *Ranunculus ficaria* L., and *Glechoma hederacea* L. are also found.

In vineyards one finds a great variety of weeds according to locality. *Stellaria media* Cyp. is generally distributed ; on account of its mass growth it is even used in some places as green manure for the vines.

5. Weeds of grassland

(a) Hay fields

Holcus lanatus L. On account of its earliness it is an especially dreaded weed of once cut fields in nearly all types of land, but especially in poor land.

Aira cæspitosa L. A dangerous tuft grass in moist, acid and moorland soils.

Molinia coerulea Moench., found especially in moorland soils.

Cyperaceae. Many species of the genera *Carex*, *Eriophorum* and *Scirpus* are common in wet and acid soils.

Juncaceae. As in the case of the Cyperaceae.

Colchicum autumnale L. A weed feared in hay crops for its poisonous properties, especially in the west and south of Germany.

Allium spp. Troublesome but not general weeds of hay fields.

Rumex spp. *Rumex crispus* L., *R. obtusifolius* L. and *R. acetosa* L. are the most injurious.

Polygonum bistorta L. is widespread in moist hay land on fairly good soil.

Lychnis flos cuculi L. Very common in moist meadowland.

Ranunculus spp. *R. acer* L. is poisonous when green and is very frequent in hay land. *R. repens* L. is similar, but less dangerous.

Cardamine pratensis L. A very early flowering, later overgrown weed of wet places.

Filipendula ulmaria Maxim. A late weed, especially of the edges of ditches.

Sanguisorba officinalis L. and *S. minor* Scop. L., used in some places for fodder, late-flowering weeds of hay land that is not deficient in lime and not too wet.

Ononis spinosa L. Found especially in poor and dry grassland.

Geranium pratense L. An associate weed of Arrhenatheretum in soil not deficient in lime.

Lythrum Salicaria L. In wet meadowland.

Anthriscus silvestris (L.) Hffm., one of the most dangerous meadow weeds in existence, is found in the first cut, especially seriously in land that has received one-sided treatment with liquid and farmyard manure.

Heracleum sphondylium L., under the same conditions and with the same serious consequences, replaces *Anthriscus silvestris* in the second hay cut.

Silaus pratensis Bess. On moorland, moist soil, especially in central and southern Germany.

Angelica silvestris L. Dangerous in wet meadowland in the south of Germany.

Pastinaca sativa L. Bes. On the edges of not too moist hayland, especially in chalk regions.

Daucus carota L. Not confined to any special kind of soil, found in hayland that is not moist.

Chaerophyllum hirsutum Vill. On wet, calcium-deficient hay land in the south of Germany, and also in East Prussia.

Salvia pratensis L. In dry meadowland rich in lime but poorly manured.

Semi-parasites on hay fields (Family Scrophulariaceae)

The species *Alectorolophus major* Rchb., *A. minor* W. et Gr. and *A. hirsutus* All. are dangerous and widely distributed ; widely distributed also, but less dangerous, are *Euphrasia odontites* L. and, in wet meadows, *Pedicularis* spp.

Plantago lanceolata L. Found especially in good soils.

Galium spp. are distributed in not too moist hay fields only when there is a deficiency of nutrients, especially *G. verum* L. and *G. mollugo* L.

Knautia arvensis Coult. In not too moist to dry meadows, especially on good soils.

Achillea millefolium L. comes to the fore in dry hay fields especially.

Chrysanthemum leucanthemum L. A very dangerous weed of fairly dry land with an insufficiently close sward.

Petasites officinalis Moench. A very troublesome associate of meadows by water courses.
Carduus spp. Found especially in dry meadow land.
Cirsium spp. The most troublesome are *C. lanceolatum* Scop., *C. rivulare* Link., *C. palustre* Scop. (on wet, moorland areas), and *C. oleraceum* Scop., especially abundant in the second cut.
Centaurea jacea L. Found especially in dry meadows of regions not deficient in lime, and, to a still greater extent, *C. scabiosa* L.
Taraxacum officinale Weber. A very common and dangerous weed of hay fields.
Tragopogon pratensis L. Associate of good hay land.
Crepis biennis L. Associate of good hay lands, especially in areas not deficient in lime.
Equisetum palustre L. On account of its poisonous properties a much feared weed of wet meadows, especially in northern Germany.

(b) Pastures

Nardus stricta L., found especially in acid and crude humus soils.
Aira caespitosa L. Frequent in pastures.
Holcus lanatus L. Also a common weed of pastures.
Juncaceae. Frequently troublesome in pastures.
Ranunculus acer L. and *R. repens* L. are common weeds of pastures, especially in heavy land.
Potentilla anserina L. is frequent in heavily grazed areas, and is a characteristic weed of goose pastures.
Ononis spinosa L., because it is not eaten by cattle, is especially common in poor grazings.
Genista sagittalis L. A weed of poor upland pastures in the hill country of west and southern Germany.
Euphorbia cyparissias L. and *E. esula* L. are frequent in well-limed, poor and sunny dry pastures.
Euphrasia spp. Frequent in humus-rich pastures.
Plantago media L. is an especially typical and dangerous weed of pastures, as is also *P. major* L. to a much smaller extent.
Bellis perennis L. is found particularly in overgrazed areas.
Achillea millefolium L. is a weed of dry pastures.
Carduus nutans L. and *C. acanthoides* L. are common in dry lime pastures.
Cirsium arvense Scop. is not only one of the most dangerous weeds of arable land, but also spreads widely in badly managed pastures.
Hieracium pilosella L. Not a dangerous weed, characteristic of impoverished pastures.
Pteridium aquilinum (L.) Kuhn. A widespread weed of poorly kept pastures on poor and crude humus soils of German hill country.

(c) Special weeds of alpine grassland

Nardus stricta L. is one of the principal weeds of alpine pasture on silica soils.
Veratrum album L. is feared in German alpine regions on account of its poisonous properties. In the south-west it is found at lower altitudes also.
Rumex alpinus L. A characteristic weed of milking places and other over-manured spots.
Chaerophyllum Villarsii Koch. Found especially in alpine meadows with calcium soils.
Dryopteris Filix-mas and *Pteridium aquilinum* (L.) Kuhn are very troublesome in poor crude humus soils.

The large number of other alpine weeds cannot be mentioned here.

C. THE CONTROL OF WEEDS IN GERMANY

PREVENTIVE MEASURES

Preventive measures consist mainly in preventing the introduction of weed seeds.

Seed cleaning is the most important of these measures. A prerequisite for the

production of seed free of weeds is the use of efficient seed cleaning machinery. Great progress has been made in this direction in Germany. With the machines employed to-day, it is possible to obtain seed of cereals, legumes and other large-seeded crops almost entirely free of weeds. Great progress has also been made in the cleaning of clover and grass and other fine seed. The most important firms in this connexion are Neuhaus at Eberswalde, Röber at Wutha in Thüringia and Saatschule at Hamburg, for fine seeds Lübke at Brieg (Breslau district).

The cleaning apparatus of threshing machines has been so much improved by the present time that by far the greatest part of the weed seeds in a crop is removed in this first process. Of actual seed cleaning machines, all sizes are made.

In the case of the larger machines a combined process is employed, incorporating the four main forms of seed cleaning in accordance with weight, size, shape, and specific weight. In more difficult cases, such as the removal of *Avena fatua* from *A. sativa*, the "table sorter" is also employed. For certain types of seed there are special machines to-day, and special appliances are also available for the removal of certain weed seeds, for example, electro-magnets for cleaning clover of *Cuscuta*.

Naturally the smaller single machines are not so effective as the large combined machines. In order, therefore, to make these advantages available to small farmers, the establishment of seed cleaning plants on a co-operative basis is becoming increasingly common. In most cases the plant is combined with a disinfection apparatus, which is under the official control of the German Plant Protection Service. By these means the farmer obtains for a slightly increased cost seed that is free of weeds and correctly disinfected. In addition to the co-operative seed cleaners, some cleaning and disinfecting apparatus is let out for hire by private individuals.

A further important step in preventing the distribution of weeds in seed is the regulation, in force since October 1st, 1935, that only seed from certified fields may be offered for sale or otherwise come into circulation. At the same time the organization for the recognition and certification of seed, already highly developed in Germany, has been newly regulated. Through this recognition and certification the farmer has a guarantee that plant stands which are heavily infested with weeds difficult to eradicate are excluded from the seed market from the outset. Thereby, together with the above-described organization of seed cleaning, it is not only assured that the buyer receives seed free of weeds, but also that the seed grower makes increased efforts to clean his fields in order to secure the recognition of his crops.

The results of the long and systematic pursuit of these two courses are not lacking. Moreover, certain weeds, which are mainly or preponderantly introduced in seed, have either diminished greatly in their distribution or have practically disappeared from certain regions. This is especially true, for example, of *Agrostemma Githago*, *Delphinium consolida*, *Bromus secalinus* and *Cuscuta epithymum trifolii*.

Progress similar to that with seed for arable land has been made in the production and trade of weed-free seed for grassland. Since the war of 1914-18, the home production of grass and clover seed has been steadily built up in Germany, and at the present day has to a great extent done away with both the importation of foreign seed, not suitable for German localities and therefore liable to encourage weed dis-

tribution, and also the formerly common practice of using the weed-infested cleanings of hay barns for sowing grassland.

A second method by which weed seeds can be distributed is through the use of farmyard manures, compost and refuse of all kinds, wherein, as is known of old, farmyard manure plays the principal part. The removal of this source of weed distribution is closely connected with efforts for improving the preparation of farmyard manure. The better this is, the more thoroughly destroyed are the weed seeds contained in the manure. Through Government subsidies for the preparation of manure and the construction of liquid manure containers, much has been done in this field within the last few years.

It need only be mentioned that the same holds good for compost as for farmyard manure. Compost made of field refuse is used as far as possible on grassland, grassland compost, on the other hand, on arable land, because any weeds still present are thereby eliminated. Other vegetable refuse used as fertilizer, especially cleanings and threshing refuse, must be so treated that it contains no more germinable weed seeds. Cleanings destined for feed must be previously ground, steamed or ensiled.

A further source of weed distribution is found in populations of weeds which become established in farmyards, by roadsides, on the edges of ditches, in woods, on dams or dikes, in railway and motor road cuttings and in other waste places. Efforts to control many weeds, especially those which are wind-borne, are of limited use only unless these populations are eradicated in good time. There are certain official regulations in Germany which ensure the eradication of such weeds at the right time. Another effective means of dealing with this question is provided in the reorganization of agricultural properties, whereby the number of hedges, ditches, roads, etc. is reduced through the bringing together of widely separated small holdings.

The introduction of weed seeds is of special importance for land newly taken into cultivation. Although, in a country so much used for arable farming as Germany, waste lands, woodland clearings or sea marshes taken into cultivation always have a certain proportion of introduced weed seeds, great care should nevertheless be taken to prevent further introductions. In addition to seed and farmyard manure, natural marl is important as a distributor of weeds. *Tussilago farfara* especially is frequently distributed in large quantities in natural marl, and, once distributed, is very difficult to eradicate. The same is true for many other forms of earth used for land improvement, such as clear sludge from starch and sugar factories, cleanings from ditches and ponds, earth from beet and potato washings, and such like. It is worthy of mention in this connexion that, in the draining of the Zuider Zee in Holland, particular care is devoted to the control of weeds in the adjoining regions in order to reduce the danger of introducing weed species into the new land.

It is only necessary to mention here numerous other methods of preventing the distribution of weed seeds, as they are generally known. These are, in the fields, the prevention of seeding (early mowing, the attachment of weed collectors to mowing machines, careful carrying, grazing of the stubble, etc.) ; in meadowland, cutting at the correct time ; and in pastures, the mowing of rank patches and of all plants which remain standing. The danger of weed distribution, moreover, is one of the reasons

Fig. 1.

Fig. 2.

Fig. 1. Winter wheat in normal rotation, almost free from weeds.

Fig. 2. Winter wheat grown for the fourth year in succession; heavy growth of *Veronica hederifolia*.

why there has been some degree of hesitancy in Germany in adopting the use of the combined harvester.

CONTROL MEASURES—CULTURAL

Cultural measures on arable land

Cultural methods take the foremost place among the means of controlling weeds in arable land. Efforts must be made, by all kinds of measures which are at the same time beneficial to the crop plants, to keep the growth of weeds as small as possible from the very outset. Cultural measures form the basis of all weed control, while the various chemical means should be regarded as auxiliary only.

The necessary condition of any successful weed control is the promotion of growth in the crop plants. Vigorous plant stands are among the best means of eradicating weeds.

Regulation of the water relations of the soil, especially through drainage, must take priority. Excessively wet fields result in stunted plant stands, but offer optimal conditions of life and reproduction for too many weed species.

The choice of the crop plant is of great importance. Any attempt to enforce the cultivation of a plant unsuited for the particular soil and climate ends in a dangerous growth of weeds in poor stands that are prey to all manner of plant diseases.

The crop rotation is just as important for weed control as the choice of the correct crop plant. If each crop is grown after its most suitable predecessor, the competition of weeds is checked through its vigour alone. Moreover, the danger of plant disease is diminished through suitable cropping, and therewith the formation of poor and patchy stands, which encourage weed growth, is to a large extent eliminated. Finally, good cropping so promotes soil activity that the life of weed seeds is shortened.

There is naturally no one rotation which is equally good in all cases and for the control of all weeds. Each rotation, on the other hand, has its own typical weeds ; and every "cleaning rotation," however good it may be in the suppression of some weeds, results also in the undesired multiplication of other species. All one-sided measures should therefore be avoided. The crop rotation should rather be so arranged that no weed association has a possibility of undisturbed development.

The greatest degree of weed distribution, especially of weeds that seed themselves, is brought about by a crop rotation having an excessive proportion of cereals. Figs. 1 and 2 show, in one and the same field, a varying degree of growth of *Veronica hederifolia* (which is greatly encouraged by the growing of wheat) after wheat had been grown in four successive years and when there had been a suitable crop rotation. But the cultivation of roots also—on the whole one of the most important methods of eradicating weed growth—when carried out successively promotes the growth of a weed flora which can eventually be extremely detrimental to the root crop (*Chenopodium album, Mercurialis perennis, Urtica urens, Galinsoga parviflora, Senecio vulgaris, Fumaria officinalis, Solanum nigrum*). The occasional growing of cereals keeps these weeds in check without any further difficulty. A constant alternation of cereals and roots is therefore desirable.

Crops which provide a heavy shade play an important part in the control of

weeds. In Germany these include in the first place rye, winter barley, forage mixtures for early cutting, rape, hemp, maize, and leafy potato varieties. Their shade not only accelerates the decomposition of weed seeds in the soil, but is very important also in the direct suppression and destruction of weeds which have already come up. Herein the time at which shading takes place, the duration of deep shading of the ground and the height of the shade are of importance.

Extensive investigations on this subject were made in 1938 and 1939 in uniform and well developed stands of a wide range of crop plants. As yet these have been published in part only (Rademacher **35**). As a measuring instrument, Dr. B. Lange's electric light intensity measure, made by the firm of Bergmann and Abtmann, Berlin, was used. This consists of a selenium half-conductor photocell and a galvanometer, which is connected to the cell by a flex, so that the cell can be moved independently of the measuring instrument. The range of sensitivity of the instrument corresponds approximately to that of the human eye, or 300 to 700 $\mu\mu$, and attains its highest point at 600 to 700 $\mu\mu$. Although not the whole of the part of the electro-magnetic radiation important for plant life was determined thereby, the most important wave-length regions could be studied. For adjacent wave-length regions still further investigations must be made, especially in regard to their importance for seed germination.

First, the development of shading was determined through weekly measurements of the illumination of the ground under the stands in comparison with the illumination of the locality. The curves thus obtained for light absorption at the foot of the plant stand gave a very striking picture of the development and the intensity of the shading. It is not possible here to go into details, but a few characteristic examples may be given. Fig. 3 shows the course of light absorption from the spring onwards in rye (Petkus), winter barley (Friedrichswert), and in a wheat variety with slow spring development (Standard). The course of the curve shows that in rye, at the decisive time of weed development in spring, shading increases considerably more rapidly than in the case of wheat. Rye is therefore much better able to suppress weeds than wheat. Fig. 4 shows the light absorption curves for oats, horse beans (*Vicia Faba*) and a mixture of the above-mentioned two crops together with *Pisum arvense* and *Vicia sativa*. The growing of a mixture of this kind is considered to be one of the best methods for suppressing obstinate root-propagated weeds in arable land. The light absorption curve shows that shading in the mixture is considerably more intense than in two of the components, is of unusually long duration and even towards harvest is but little diminished. Such an ideal course in the light absorption curve—rapid increase of shading, long duration of deep shade, little reduction of shade towards harvest—is found in only a few other crop plants, for example, rape (*Brassica Napus oleifera*). In contrast, Fig. 5 shows the corresponding curve for the poppy (*Papaver somniferum*) ; as this species is lacking in all the characters just mentioned, it is one of those plants with only a limited capacity of suppressing weed growth. At the same time, however, this illustration shows to what extent the shading capacity of crop plants can be increased by abundant manuring.

Shading capacity can also be increased by varying the density of the stand,

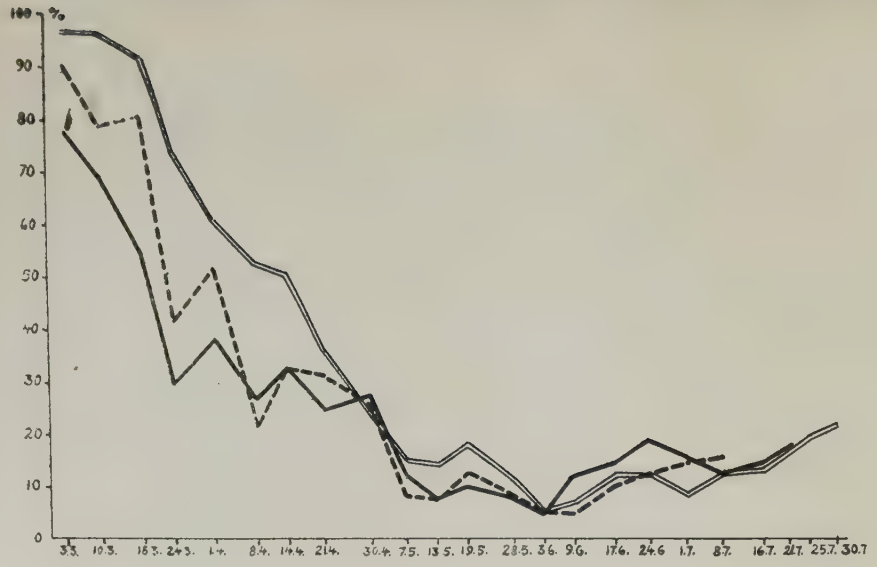


FIG. 3.

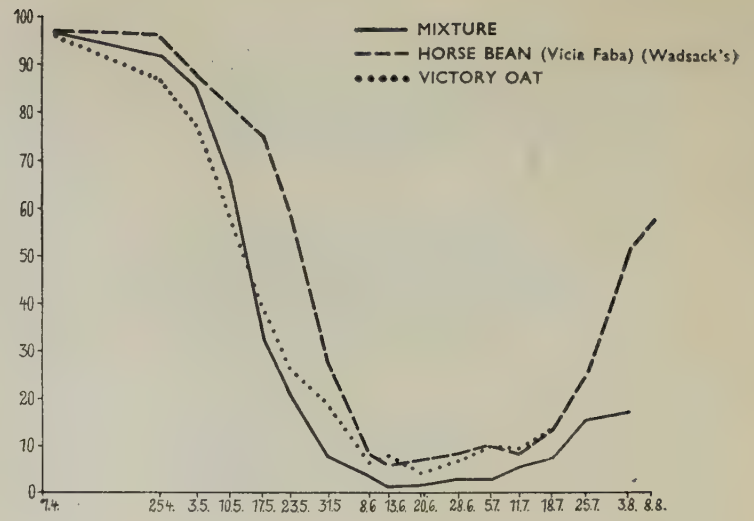


FIG 4.

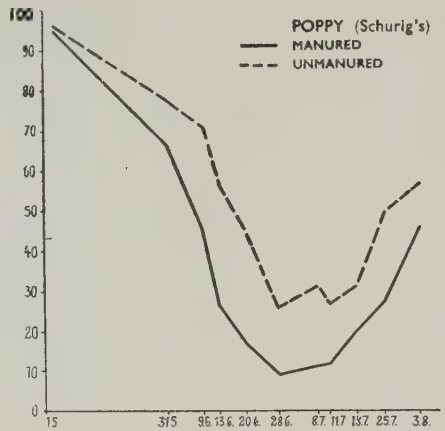


FIG. 5.

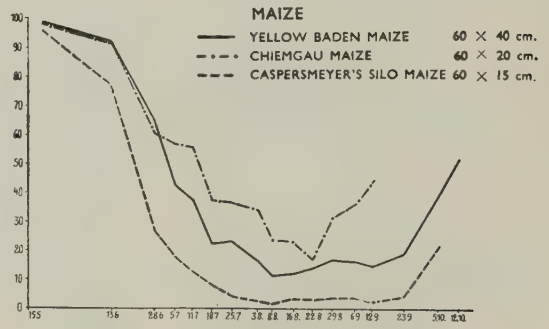


FIG. 6.

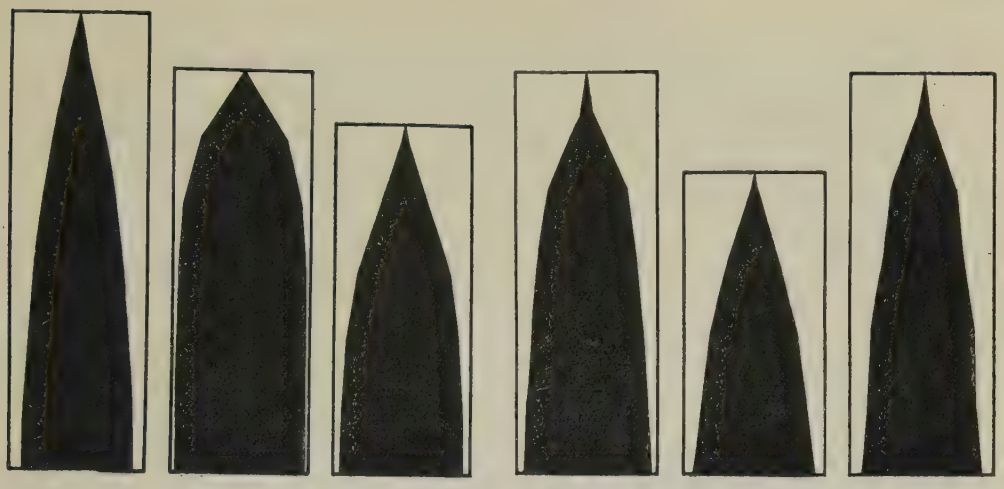
FIGS. 3, 4, 5 and 6. Course of light absorption under various crops. In each case abscissae = date of measuring, and ordinates = light in the stand in percentage of the light outside. Crops studied are shown in each figure, except in Fig. 3, where solid line = winter rye, broken line = winter barley, and double line = winter wheat. Fig. 5 shows the effect of different manurial treatment on poppies, and Fig. 6 the effect of different planting distances on maize.

especially by the use of closer drills. Further, considerable varietal differences in the course of light absorption also exist within each plant species. Both can be seen exemplified in maize in Fig. 6. The upper curve shows conditions in an early ripening and rapid-growing grain maize which is generally sown in wide drills and with wide planting distance. The lower curve was obtained for a silo maize, which is grown in close drills in order to obtain heavy green weight. Similar varietal differences (although perhaps only occasionally, as in the case of potatoes, equally marked) are found in nearly all crop plants, a fact which should be taken into consideration in reference to the control of weeds.

Measurement of the light absorption on the ground is, however, not alone sufficient to determine the shading capacity of a crop plant, but light absorption at different heights of the stand must likewise be considered. For it is of decisive importance that weeds must be prevented not only from shooting up, but that those weeds which have nevertheless come up with the crop and are capable of development (Scheer **36**) shall be as far as possible prevented from flowering and seeding. That can only be done when those crop plants are grown in which shading does not—in an upward direction—diminish too rapidly. Many plants, for example many legumes, exhibit indeed a capacity for heavy ground shading, but, on account of their insignificant height, shading in an upward direction diminishes too rapidly and suddenly, and permits the weeds which have come up through the crop to flower and fruit undisturbed. For this reason I carried out, in the principal crop plants, measurements of light absorption at different heights of the stand, and obtained thereby—in schematic presentation of the light conditions compared with the external illumination—"shade cones." Three such shade cones of good weed suppressors are shown in Fig. 7. The most ideal shade cone is found in hemp (*Cannabis sativa*), in which the ground shade is perpetuated almost undiminished to half the height of the stand, and even further up it becomes reduced only very slowly. Rye and maize also, which had not yet reached the height of their development on the day the measurements were taken, exhibit a slow diminution of shading in an upward direction.

In all this the height of the plant stand naturally plays an important part. The higher the stand, the more slowly the shading diminishes. It is comprehensible that here also considerable differences exist between the different varieties of one and the same species. In particular, the breeding of short-strawed cereals for the production of strength of straw and easily mown stands has had an unfavourable effect upon capacity for shading. Fig. 8 shows the shade cone for three German varieties of oats, which represent extremes in this respect. It is obvious that, with the same rate of early development, the short-strawed variety (in the centre) requires much more assistance in its competition with weeds than the long-strawed variety, a fact to which attention has already been directed on a previous occasion (Rademacher **34**).

A further important function within the crop rotation is performed by the forage perennials, that is, clover species and especially lucerne. To a certain extent they take an intermediate position between actual arable land and permanent grassland, so that in them neither typical arable nor grassland weeds can become multiplied. Shading or mowing destroy the few seed-propagated weeds which germinate in the



1 2 3 4 5 6

FIG. 7. FIG. 8.

FIGS. 7 and 8. Shade cones of (1) winter rye, (2) hemp, (3) maize and (4, 5 and 6) oats. The rectangles represent a section of the stand; the black cones, the amount of light absorbed at the different heights of the stand.

(1) Petkus rye. Height 170 cm., almost ripe, 19.7.38.
(2) Schurig's hemp. Height 150 cm., in full leaf, 19.7.38.
(3) Caspersmeyer's silo maize. Height 130 cm., not yet fully developed.
(4) Victory oat, height 140 cm., milk-ripe, 19.7.38.
(5) Heine's silver oat (very short-strawed), height 105 cm., yellow ripe, 19.7.38.
(6) Rotenburg black oat, height 140 cm., ripe, 19.7.38.

unchanging upper layer of the soil. But many weeds propagated through their root system, *Cirsium arvense* in particular, are unable to tolerate mowing and in due course die back. It is true that, with increasing age and under poor management, a characteristic weed flora arises in clover and lucerne fields also and necessitates ploughing up sooner or later.

Fallowing, excellent for the control of weeds, has—with the increasing population and intensified use of the land—almost entirely disappeared from Germany at the present day. On the other hand partial fallowing, after early harvested crops or before crops which are planted late, plays an important part, especially in the destruction of certain root-propagated weeds such as *Triticum* (= *Agropyron*) *repens*.

In discussing the importance of the choice of crop and crop rotation in the control of weeds, it should not go without mention that many crop plants, in addition to their capacity for suppressing weeds mechanically, also possess other means of keeping weeds down, a fact to which Kuhn (**23, 24**) drew attention some years ago. The nature of this means of control is not yet known, whether it is a question of root excretions or gaseous excretions from the whole plant having a direct action (somewhat in the sense of Molisch's "allelopathy," **30**), or whether it is an indirect influence exercised upon the soil and soil microflora. Thus rye—above and beyond its mechanical powers—suppresses the shooting of weeds to an incomparably greater degree than does wheat.

As an example, a summarized account may be given of the result of two pot trials carried out in the winter of 1938-39, of which No. 1 took place in sand-loam soil in the open, No. 2 in sand and loam soil in a heated glasshouse. The shooting and development of *Anthemis arvensis* and *Matricaria indora* under rye and wheat were observed. Table 1 gives the number of weeds per pot in an average of four pots when 100 weed seeds were sown in each. The number of cereal plants amounted to twenty per pot.

Table 1.—Development of Anthemis arvensis and Matricaria indora under rye and wheat.

(*a*) *Anthemis arvensis*

in

Experiment No.	Cereal	Sand			Sand-loam			Loam		
		7/1	9/2	18/4	17/11	1/12	23/3	7/1	9/2	18/4
1	rye				12.3	13.5	15.8			
	wheat				23.0	25.8	24.8			
2	rye	10.7	11.0	7.6				9.0	9.8	6.8
	wheat	11.2	11.3	6.3				11.2	13.7	12.0
	no cereal	13.7	16.3	14.7				11.3	15.3	16.3

(*b*) *Matricaria indora*

in

Experiment No.	Cereal	Sand			Sand-loam			Loam		
		7/1	9/2	18/4	17/11	1/12	23/3	7/1	9/2	18/4
1	rye				25.8	28.3	7.5			
	wheat				39.5	39.5	10.5			
2	rye	31.5	25.5	18.7				26.5	25.2	15.0
	wheat	33.5	32.2	34.0				24.5	22.0	23.5
	no cereal	36.7	40.6	39.3				24.3	25.3	24.3

It is not possible in this connexion to go into details concerning the individual results and their dependence on soil, temperature, etc. We can, however, note in general that in the rye pots the shooting of the two weeds was less than in the wheat

pots, and that especially in the course of the winter the number of weeds under rye was much more greatly reduced than the number of those under wheat. This is particularly clear in experiment No. 2, in which, on account of its being carried out in a glasshouse, injury through frost was eliminated. It will be of scientific interest and likewise of practical importance to study the causes of this phenomenon, which has been observed in the case of other crop plants also.

In addition to the choice of suitable crop species and a good crop rotation, the choice of variety is important. I have already drawn attention to this in discussing the effect of shading, with reference to previous work (Rademacher **34**). A second point of view is the resistance of the different varieties to plant diseases and pests. A susceptible variety forms loose stands or loses its leaf weight early, so that its cultivation is always followed by a considerable increase of weed growth. This possibility, therefore, should always be borne in mind.

In Germany great importance is attached to tillage as a means of controlling weed growth. It begins in the autumn, immediately after the cereal harvest, when the stubble is scaled. In this way those weeds are destroyed which—in spite of mowing—are in a position to shoot again (see Fig. 9). Scaling is considered valuable also for the eradication of *Triticum* (*Agropyron*) *repens*. It further brings about the burying of many weed seeds that have fallen out before after-ripening, thereby exposing them to more rapid destruction by the soil bacteria, as has been noted by Wehsarg (**45**). Finally, scaling encourages many weeds to shoot and they can then be destroyed through autumn ploughing.

The aim of tillage in the spring should be to induce germination in as many weeds in the upper soil layer as possible, so that they can be destroyed when the work of sowing is carried out. The earlier a field dries up as a result of good drainage the sooner can harrowing be begun. The implements employed for this purpose are sometimes very simple and sometimes of a more complicated nature. Among the latter may be mentioned the adjustable "knife harrow," manufactured by the firm of Harder, of Lübeck, and others.

In spring sowing, the object is to avoid bringing to the surface new soil layers containing weeds, to encourage the growth of the crop as much as possible, and to hinder that of weeds. Early sowing of vigorous seed with good germination capacity by means of drills and, where feasible, a roller, has proved generally successful. Where there is a heavy growth of weeds, the drills are more closely placed and the seeding rate is increased with a view to increasing shade.

Especial importance is attached in Germany to the care of young sowings. It begins three or four days after sowing, even before the crop plants and weeds come up, with " blind hoeing " or "blind harrowing," especially in the case of cereals and beets. The adhesion of germinating weeds to the particles of earth is thus broken and they die back. The hoeing and harrowing are repeated as far and as long as the crop plants permit. Of winter sowings, only winter barley can as a rule be harrowed, on account of the weather in autumn. In this case corrosive fertilizers are used as weed-killers (see later chapter).

The care of new sowings and the control of weeds in summer sowings have

received a considerable impetus in recent years through the introduction of the movable jointed harrow with very closely set tines. The individual tines can move independently side by side, so that the harrow adjusts itself closely to the surface inequalities of the ground. As there are as many as fifty-four tines to one metre working breadth, it is hardly possible for a single weed seedling to escape the harrow. These jointed weed harrows are now made by various German firms, after the pattern of the implement manufactured by Rudolf Sack, Leipzig (Figs. 9 and 10). Farmers have been very quick to adopt them. In 1932, for example, only six years after the appearance of the first jointed harrow, approximately eleven thousand of these implements were in use in Bavaria (Fürst **14**). Their introduction represents one of the most important advances in weed control in Germany within the last ten years.

" Blind harrowing " has been increasingly adopted in recent years, not only for the cultivation of cereals, but also for that of roots (sugar beet, fodder beet, turnips, potatoes). For later cultivation and weed control in root crops hoeing machines are employed on the larger farms, but the smaller farms to-day make increasing use of " multiple implements," or implements in which the working parts are interchangeable and which can therefore be used for a great variety of purposes.

Owing to the improvement and wider use of implements and machines of this kind, it has become increasingly rare in Germany to employ manual labour for the control of weeds. It is true that in the case of some crops (turnips, potatoes, linseed) and for the destruction of certain weeds (*Cirsium arvense, Colchicum autumnale*, many rosette weeds in clover and lucerne) it is impossible to dispense with it entirely.

I cannot go into further details here, my aim being to note what is of most importance and characteristic of Germany.

The use of fertilizers for weed control has recently become of considerable importance in Germany. The necessity for an intensive use of the land as a result of over-population has brought about a very heavy use of manures. Only in a few small countries (Belgium, Holland, Denmark) is the use of manures higher per unit area. It is natural that an attempt should be made to utilize this greater quantity of synthetic fertilizers for the simultaneous control of weeds. In this field also satisfactory progress has been made within the last twenty years. Manurial treatment can be employed in the service of weed control in two ways : (1) directly, in the destruction of germinating weed seeds and young plants ; (2) indirectly, through the crop plants. I shall have more to say on the first-named method in my subsequent discussion of chemical means of control. The following remarks deal solely with the indirect suppression of weeds by means of the crop plants. This again may take place in two ways, either through the soil, or through the crop plants.

The action of organic manures is shown principally in an increase of the bacterial life of the soil. Wehsarg's research has shown that the more active and rich in bacteria the soil is, the sooner do weed seeds lose their capacity for germination. Every encouragement of bacterial life through the application of farmyard manure, green manure and other organic fertilizers, therefore, contributes indirectly to a reduction of weed growth.

A further important possibility of controlling weeds consists in the alteration of

soil reaction through manurial treatment, in particular the neutralizing of acid soils by liming and the employment of alkaline fertilizers. By these means all weeds governed by acid soil conditions (*Scleranthus annuus*, *Spergula arvensis*, *Rumex acetosella* and others) are eradicated without any other measures being necessary. Even dangerous species such as *Holcus mollis*, otherwise difficult to control, may be rapidly and entirely eradicated in this simple manner. The simultaneous increase of vigour in the growth of the crop plants does the rest. A suppression of calciphilous weeds through the application of acid fertilizers is certainly possible, but, on account of unfavourable secondary effects, is of no practical importance.

At the same time it must not be overlooked that while the alteration of soil reaction suppresses certain weeds, it is liable simultaneously to encourage other weeds. Thus the acidity-loving species *Raphanus raphanistrum* may be gradually suppressed through liming, but at the same time favourable conditions are created for the more calciphilous and equally dangerous species *Sinapis arvensis*.

The control of weed flora through manurial treatment by way of the crop plants must be based upon the consideration that, under normal conditions, manuring encourages the growth of all plants, that is, both the crop plant and the weed. In well-manured fields, therefore, weeds as well as crops find especially good growth conditions. The art of employing this method consists in causing the manurial treatment to benefit in the first place the crop plants, and to ensure, through their increased vigour, as great as possible a suppression of the weeds at the same time. The struggle between crop plant and weed is a competition for space, light, water and nutrients. It is necessary at the outset —through the previously described methods of weed destruction at the time of sowing and directly afterwards—to give the crop plants an advantage at the start, and at the same time through abundant manuring to place them in a position to maintain this advantage.

It is therefore important that they should have abundant access to all nutrients, of which nitrogen is without doubt most important. By encouraging the vegetative growth in particular, it leads to luxuriant leaf formation, to considerable growth in height and therefore to abundant shading. Fig. 11 shows how early such differences are seen and how decisive the exact timing of such manurial treatment is. This illustration shows (to the left) the effect of a nitrogenous fertilizer on weed growth in winter barley. The increased effect of shading and therewith the suppression of weed growth can be numerically demonstrated also, by means of light measurements (see also Fig. 5).

As the individual weed species have different light requirements, the manurial treatment of the crop plants has therefore a different effect upon the different species. *Vicia* species are especially sensitive to shading and therefore particularly easy to suppress by nitrogenous fertilizers. I was able to demonstrate that the proportion of *Vicia hirsuta* was greatly diminished in winter barley by the use of nitrogenous fertilizers (Rademacher **34**). Fig. 12 may be taken as an example of this. It represents the harvest obtained from plots of winter barley and *Vicia hirsuta*, 25 sq. m. in size, in one case unmanured and in the other manured with 40 kg. nitrogen per hectare in the form of nitrochalk. The difference in the growth of the *Vicia* is very

striking. Pot trials showed that this reduction in the growth of the vetch is not based on the often asserted unfavourable action of nitrogenous fertilizers upon legumes in itself. The results for the dry weight obtained on an average of four pots are given in Table 2.

Table 2.—Yield of vetch under ascending doses of nitrogen

Species	Air-dry weight per pot		
	No nitrogen	4.6 grm. NH_4NO_3	9.2 grm. NH_4NO_3
	grm.	grm.	grm.
Vicia hirsuta	39.8	42.9	42.5
Vicia tetrasperma	29.3	31.1	29.0
Vicia angustifolia	38.4	32.3	36.3
Sinapis arvensis for comparison	19.8	88.1	115.9

On the other hand, in another pot trial with three common weeds, special sensitivity to light was demonstrated in *Vicia hirsuta*. *Stellaria media*, *Sinapis arvensis* and *Vicia hirsuta* were grown in earthenware pots of 9 litre soil capacity (a) under normal lighting conditions, and (b) shaded by a cloth frame which allowed 27.3 per cent of the daylight to penetrate. This deprivation of light corresponds approximately to conditions at half the height of a good stand of cereals. The production of dry matter in the fully illuminated pots being equivalent to 100, production in the shaded pots (on an average of four pots) was 83.7 for *Stellaria media*, 65.3 for *Sinapis arvensis* and only 48 per cent in the case of *Vicia hirsuta*. *Vicia hirsuta*, and probably also the other *Vicia species*, must therefore be considered as particularly sensitive to light.

Finally, in terminating this section, mention is made of the fact that the increased use of fertilizers in Germany is bringing about a quite perceptible alteration in the proportion of the different weed species. Many species which were formerly very common as field weeds, and are still common to-day in extensive regions, are rapidly disappearing from districts where there is a considerable employment of fertilizers. On the other hand, certain weeds of ruderal character are coming to the fore even in arable land, particularly in regions devoted to field horticulture. This development requires careful observation.

Cultural measures on grassland

On the whole one is bound to admit that the cultural suppression of weeds in grassland has not yet been so well studied as in the case of arable land.

To a still greater degree than in arable land, the causes of weed growth in grassland must be examined as a basis of measures for its suppression. These causes, according to Klapp (**17**), may be the following :

(a) Where conditions are equally bad for the growth of the good herbage species :

1. Considerable acidity and impoverishment of the soil ; accumulation of crude humus in hill country (*Nardus stricta*, heath plants, broom species, moss, lichens, *Rumex acetosella*, *Polygonum bistorta*).
2. Deficiency of nutrients, humus and water in not too acid to well-limed soils (*Salvia officinalis*, *Euphorbia cyparissias*, *Centaurea* spp., *Chrysanthemum leucanthemum*, *Carlina acaulis*, *Daucus carota*).
3. Wet, impermeable soils, having water springs, excessive watering (large *Carex* spp., *Juncus* spp., *Luzula* spp., *Phragmites*, *Equisetum* spp., *Cirsium oleraceum* and *C. palustre*, *Petasites officinalis*, etc.).
4. Humus soils which have become too loose (*Holcus mollis*, *Urtica*, *Galium*).
5. Shading (*Aegopodium podagraria*, *Ranunculus ficaria*, *Glechoma hederacea*).

(b) Where growth conditions for good species are in themselves good :

1. Bare patches in naturally formed swards, too sparse or unsuitable sowing, freezing (*Ranunculus repens*, *Taraxacum officinale*, *Bromus mollis*).
2. Over-grazing (rosette plants such as *Bellis perennis*, *Plantago media* and *P. major*, *Taraxacum officinale*).
3. Excessive manuring (Umbelliferae, *Rumex* spp.).

The different cultural means of controlling weeds must be adapted in relation to these causes of their appearance.

In the first place, attention must, as in arable land, be devoted to the regulation of water conditions (drainage or irrigation). In the case of the natural meadow associations, the factor water plays so decisive a part that its importance cannot be too highly rated.

The second condition requisite for the control of weeds in grassland is, as in arable land, the encouragement of the growth of the cultivated plants by good nutrition. This is a question not only of manurial treatment in the limited sense, but also of the removal of acidity and the supply of humus.

Harmonious treatment is of great importance, as any one-sided employment of a single nutrient or some nutrients always results in an encouragement of certain weeds. For example, by the employment—usual in the German alpine regions—of diluted or undiluted liquid manure, rich in nitrogen, potassium and growth hormones, but poor in phosphoric acid, certain weeds (*Anthriscus silvestris*, *Heracleum sphondylium*, *Rumex alpinus*) have been encouraged at the expense of the grasses.

Nor should we lose sight of the fact that through the heavy employment of fertilizers the lignification of many weed species can be retarded and their nutrient value thereby increased. Promising experiments in this direction have recently been made with *Nardus stricta* in alpine regions, especially by Schneiter (**38**).

The greatest importance of manuring for weed control consists, however, in the production of a close sward wherein the bottom grasses, especially important for this purpose, predominate. This not only suppresses the weed growth present, but also prevents the germination of new weed seeds. Its importance is not fully understood until one takes into consideration the very slow development of the large grassland weeds, confirmed by recent research (Kauter **16**).

The maintenance of a close sward is therefore the most important object in the

management of hay land. It is not possible to go into details here, and I shall content myself with stressing the great importance of the roller. The roller makes the soil moister and more active. The formation of crude humus and therewith the species encouraged by crude humus become insignificant. Weeds with creeping and erect basal axes are much injured by pressure, those with deep rhizomes are prevented from shooting. The roller is indispensable in the control of the poisonous *Equisetum palustre*. As it moreover encourages the tillering of grasses, it has an indirect effect upon weed growth through the improvement of the sward. Rolling is of real value, however, only when it is carried out regularly.

Further possibilities of eradicating weeds in hay land are presented in the regulation of the time of cutting, the number of cuts taken and periodic grazing. Through early cutting the seeding and therewith the wider distribution of early-flowering weeds can be held in check. By frequent cutting one can gradually suppress many large herbaceous weeds through the repeated weakening of their subterranean parts. A better and more reliable effect is obtained, however, by the periodic use of the meadow as pasture. The same effect as that produced by a roller is obtained from the treading of the animals, but in a still more marked form. By the cropping of the animals a weakening and finally the starvation of dangerous root-propagated weeds such as *Anthriscus silvestris*, *Heracleum sphondylium*, *Rumex* spp. and *Galium* spp. are obtained. Treading and cropping cause perpetual loss of sap, prevent the storage of nutrients and the formation of seed and so in the course of time bring about the disappearance of even the most persistent weeds, while on the other hand the tillering of the grasses is encouraged. Sheep have the most intensive effect, horses less and cattle still less. It is important that grazing should be done at a time when the main development of the weeds to be controlled takes place. Grazing is thus necessary in one case in the spring, in another case in the summer, and must generally be continued throughout several years if complete success is to be obtained.

Just as the typical hay field weeds may be controlled by periodic grazing, typical pasture weeds can be suppressed by mowing. Here also it holds good that success can only be assured through the repetition of the process. The modern form of pasture management now becoming increasingly common in Germany, which consists of division into small paddocks and frequent rotation of the grazing animals together with periodic mowing, will contribute greatly to the suppression of weeds arising from the one-sided use of grassland.

The greatest danger to be encountered in pastures is the formation of gaps in the sward, as weeds at once take possession of any bare spaces. The formation of gaps arises through heavy grazing (over-stocking) accompanied by insufficient manuring. Special encouragement is given to species which are not relished by animals and to rosette weeds, of which *Plantago media* is the most dangerous in Germany. All other necessary measures for the care of pastures, such as mixed stocking, the spreading of dung heaps, mole hills and tufts, and the mowing of the surplus herbage, serve at the same time to control weeds.

In grassland also the complete eradication of weeds is not always possible without manual labour. Many weeds such as *Plantago media*, *Colchicum autumnale*,

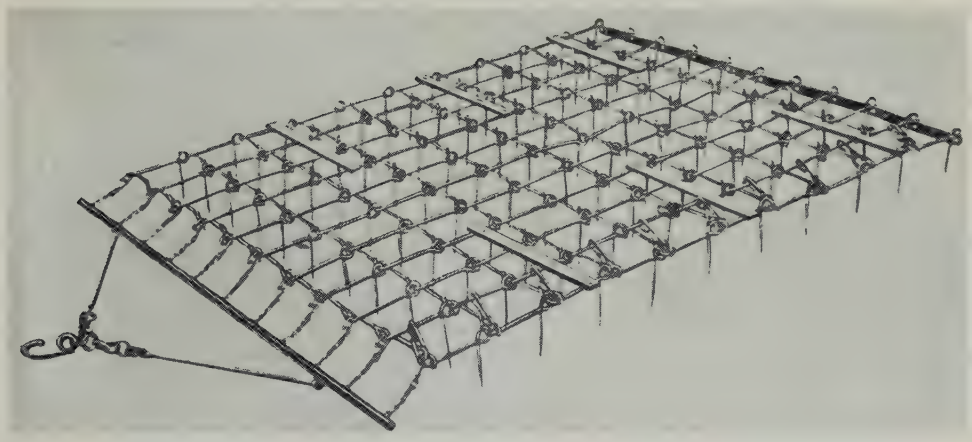


FIG. 9.

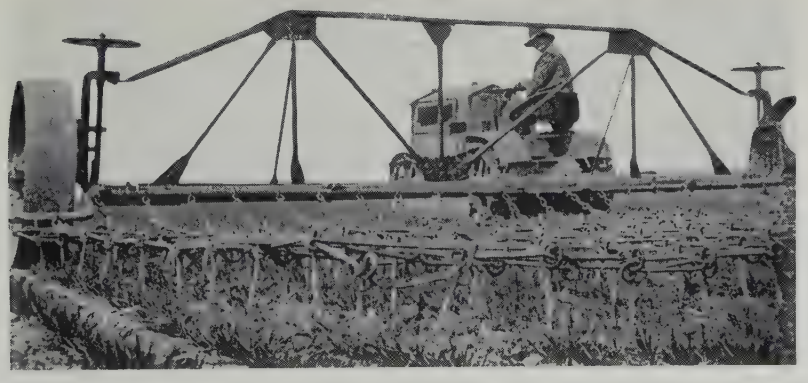


FIG. 10.

FIG. 9. Jointed harrow for weed control, made by R. Sack, Leipzig. Photograph by Sack.

FIG. 10. Sack's weed harrow, wide pattern, drawn by a tractor. The great length of the tines and the adaptability of the harrow to surface inequalities are seen. Photograph by Sack.

FIG. 11.

FIG. 12.

FIG. 11. Early suppression of weeds through good manuring (left).

FIG. 12. Harvest of barley and *Vicia hirsuta* from two 25 sq. m. plots. Left, no nitrogen; right, 40 kg. nitrogen per hectare (great suppression of the vetch). Photograph by V. Huppert.

FIG. 13a.

FIG. 13b.

FIG. 13. Condition of loam soil under the continuous application of potassium (a) in the form of 40 per cent potassium salt (soil normal) and (b) in the form of kainit (soil muddy).

Fig. 14.

Fig. 15

Fig. 14. Action of calcium cyanamide on the soil, suppression of weeds in white cabbage (F. Jancke).

Fig. 15. Effect of a selective weed-killer, in this case calcium cyanamide, on *Sinapis arvensis* in a summer cereal. Photograph by Koning.

Veratrum album, large *Rumex* species and other herbaceous plants can be entirely eliminated only by hand.

If weed growth has become very serious, it is necessary to plough up and to resow after a period of use as arable land. In resowing, plant sociological data are employed to-day as the basis for the compounding of seeds mixtures, because otherwise the so-called " famine " arises after a few years and the sward becomes heavily overgrown with weeds. For the same reason efforts are made to use indigenous seed only. Plant sociological surveys of the original flora are now used with most successful results in the laying down of aerodrome grounds and in the plantation of woodlands along the Government motor roads.

Finally, reference should be made to endeavours to render poisonous weeds innocuous. In the case of some species, such as the widely distributed *Ranunculus acer*, this can be successfully done merely through drying the forage. Other species, on the other hand, such as *Colchicum autumnale* and *Equisetum palustre*, are still poisonous even after drying. In the latter plant, Bünger and Glet (**6**) have shown that the poisonous properties can be eliminated by fermenting the hay for at least eight days at a temperature of from 60 to 70°C., as is done in the Dutch " stack " process.

CONTROL MEASURES—CORROSIVE FERTILIZERS

Chemical means of control may be grouped under fertilizers with a corrosive action, which can be used as weed-killers (corrosive fertilizers), and actual chemical means of control. We will discuss the fertilizers first.

The discovery that many commercial fertilizers act as weed-killers dates from forty years ago. Independent of one another, Heinrich in 1899 and Stender in 1900 found that solutions of Chile saltpetre, ammonium sulphate and 40 per cent potassium salts were just as effective weed-killers as solutions of iron sulphate. The discovery had at first no practical results, and not until ten years later was more intensive work done in this field by Remy and other workers. Thereby two fertilizers in particular came to the fore : kainit and calcium cyanamide.

Kainit

In chemical composition kainit is a double salt having the formula $MgSO_4.KCl.3H_2O$, to which a whole series of other secondary salts belong. Of these, reference is made only to NaCl and $MgCl_2$ as the most important. The proportion of chlorides varies greatly in accordance with the origin of the salts, which is not without significance for their efficacy as weed-killers.

For the purposes of weed control, a special form of kainit is prepared in Germany under the name of " Charlock kainit " or " dust kainit ". This is guaranteed to have

1. a K_2O content of 12 to 15 per cent, and
2. a certain degree of fineness : 50 per cent must be able to pass through a 0.25 mm. mesh sieve and a further 30 per cent through a 0.5 mm. mesh sieve.

For the effectiveness of dust kainit, the facility with which it may be dusted is,

in addition to sufficient fineness, of especial importance. Dusting facility is reduced as the proportion of markedly hygroscopic secondary salts, for example $MgCl_2$, is increased. This is regrettable in that, according to Vaster's investigations, these salts exhibit the greatest efficacy as weed-killers.

This effect is based in the first place upon plasmolysis. The concentrated salt solution reaching the leaves and stems withdraws water from the plant cells until the osmotic equilibrium is restored. This process is continued within the plant from cell to cell. At first it is still reversible. If, therefore, suction action of the salt solution is interrupted through the drying up of the solution or through washing off, the plant can make the loss good by replacing the lost water from the neighbouring tissue and finally from the roots, and can make the plasmolysis of no effect unless it is already too far advanced. If the plasmolysis is already of long duration, however, and large parts of the tissue are attacked, recovery is no longer possible and the affected cell parts must die back.

From this two facts follow :

(1) Kainit is effective only in solution. Therefore it is employed only on moist ground or on plants that are wet with dew or rain.

(2) Kainit must be able to exercise its action over a long period or repeatedly, as a solute. For this, weather, in particular humidity and dewfall together with an absence of heavy rain, is of decisive importance.

This subject will be discussed in more detail later in this article.

Good distribution is very important for effectiveness. This can be obtained only through the use of material that is sufficiently finely ground and easy to dust. For this reason, as I have already mentioned, the proportion of markedly hygroscopic salts, in themselves desirable, must not be too high.

Reference should be made here to some unfavourable characters of kainit, especially as the quantities employed for use as a weed-killer are not insignificant. In the case of heavy soils there is a danger of kainit producing a muddy and sticky condition (see Fig. 13). This danger, it is true, is not encountered in light soils ; but here, on the other hand, the removal of calcium involved in the application of kainit is not unimportant. This danger must therefore be met by a corresponding application of lime. Finally, in the use of large quantities of kainit for winter cereals, the effect of cold (especially when the application is followed by frost) must be carefully considered, as it can lead to much injury to the cereal.

Calcium cyanamide

Commercial calcium cyanamide contains to-day approximately 20 per cent nitrogen and 60 per cent CaO. Nitrogen in the form of calcium cyanamide is not available as such to the higher plants. Through various changes connected with the absorption of water it is finally transformed in the soil to ammonia, which after nitrification is available to plants. The different stages of this transformation are as follows :

1. Calcium cyanamide by reaction with water is rapidly transformed into cyanamide and calcium hydroxide :

$$NCNCa + 2H_2O = NCNH_2 + Ca(OH)_2$$

2. Cyanamide is transformed in the soil under the influence of inorganic catalyzers and (according to recent research by Schmalfuss) under the influence of micro-organisms also, under further reaction with water into urea :

$$NCNH_2 + H_2O = CO(NH_2)_2$$

3. The urea is then transformed through micro-organisms under further reaction with water into ammonium carbonate :

$$CO(NH_2)_2 + H_2O = (NH_4)_2\ CO_3$$

The ammonium carbonate can then be further nitrified. The course of this transformation has been in the main elucidated by Kappen, Löhnis, Stutzer and Schmalfuss (see 2 above).

In addition to the normal form of calcium cyanamide decomposition, dicyanodiamide can also be formed through polymerizing under certain conditions (especially under wet storage conditions, although not in arable land). This dicyanodiamide was formerly considered to be particularly injurious to plants. According to recent research, however, that does not seem to be the case.

It is rather the cyanamide that is generally believed to be the part injurious to plants and therefore decisive for the killing of weeds. Kappen certainly leaves it an open question whether the marked basicity of the calcium cyanamide solution—greater than that of any other calcium compounds, especially in a nascent state of the calcium hydroxide—may not participate in producing the injury.

In contrast to kainit, which in the main affects only the leaves of plants, in the case of calcium cyanamide we distinguish between action on the leaves and on the soil (roots). In accordance with external conditions and the species of weed concerned, it is now the action on the leaves and at another time the action on the soil that comes to the fore.

As the cyanamide is the actual part of the fertilizer which injures the plant, the injuries (to weed and crop plant) are so much the greater, the longer the action of the cyanamide. Its rapid decomposition takes place :

1. when there is a considerable amount of moisture (that is to say, especially in the form of rain, which is the more detrimental to the success of the treatment the sooner it falls after the application of the fertilizer),
2. in the presence of great quantities of inorganic catalyzers (ferric hydroxide, manganese peroxide and others),
3. in humus and therewith bacterially rich soil.

In practice this means that calcium cyanamide, so far as radical action is desired, must be dusted on to the plants when they are damp ; but if, on the other hand, too severe reaction is to be avoided on account of the crop plants (winter cereals), it should be dusted on the dry plants. If an effect upon the soil is required, the fertilizer must be dusted on the ground when it is moist (that is, not dry and also not too wet). In good soils rich in bacteria, the cyanamide will be decomposed at once through the bacteria in the uppermost soil layer and will destroy there the superficial roots of the weeds, but not the deeper roots of the crop plants. On light soils, on the other hand, on account of its slower decomposition it can penetrate to the lower soil layers and thereby injure the roots of the cereals.

The actual manner in which cyanamide acts is still unknown.

Of the different forms of calcium cyanamide, the " unoiled calcium cyanamide "

is most effective as a weed-killer, because it can be readily distributed. The " oiled " calcium cyanamide has certainly a good effect upon the soil, but is definitely inferior to the first-named in its effect upon leaves. The " granular " and " pearled " forms are not satisfactory as weed-killers.

The main disadvantage of employing calcium cyanamide is that it is very disagreeable to handle, and that through its application a field sometimes receives excessively large and untimely quantities of nitrogen, conducive to lodging, retarded ripening, etc.

The disadvantages of unilateral application of either of these two fertilizers early suggested that it might be well to mix them, thereby reducing their quantity, supplying the soil with two nutrients instead of one, and improving the distribution. Remy found as early as 1914 that a mixture of 0.75 dz. calcium cyanamide per hectare and 7.5 dz. kainit per hectare did more damage to *Centaurea cyanus* than a double quantity of either of the two components separately. This finding has since been confirmed by numerous workers, a narrowing of the ratio of the two fertilizers to approximately 1 : 6 having been found more suitable.

The advantages of controlling weeds by means of fertilizers are obvious ; since plant nutrients are applied at the same time as the weed-killers, no extra cost is incurred. For this purpose, however, it is necessary that plans for manurial treatment should from the outset take into consideration this form of application. No special apparatus is necessary. The dusting may be done by hand, or still better by the use of a good manure distributor, such as can be found on any large farm. The disadvantages of the method, in addition to those already mentioned, consist mainly in the fact that success is dependent upon weather conditions. When it is remembered, however, that other chemical means of control are also dependent upon the weather, although not to such an extent, too much importance should not be attached to this circumstance.

Corrosive fertilizers may be used for the control of weeds germinating in the soil or seedlings which have already come up. At later stages weeds are as a rule insufficiently damaged by this method of control.

The use of fertilizers for destroying germinating weeds

The object of this form of weed control is to employ commercial fertilizers shortly before or after the sowing of a wide variety of crop plants in the course of the year for the destruction of germinating weeds. It is only in very recent times that this method has received closer attention, and findings are based rather on experience than on systematic experimentation. The difficulty of the method is that the crop plants, germinating at the same time as the weeds, may also be injured, especially in soil with slight powers of absorption, in cold weather, and when there is a lack of rain for any lengthy period. The fullest work yet done on this subject is by Weigert and Weizel (**47**). Their experiments were mainly concerned with *Anthemis arvensis*, but their findings, according to all other experience, also hold good for most other weeds.

Of the potash fertilizers, those containing chlorine have a better effect than the

sulphates. Kainit has by far the best effect of all, to no small extent because, on account of its low K_2O content, it is used in larger quantities than salts of a higher percentage. After kainit follow, in descending order of effect, 40 per cent potash salt, 50 per cent potash salt, sulphate of potassium and potassium magnesium sulphate.

Of the phosphatic fertilizers, superphosphate is the only one tested up to the present and in its effect it has been inferior to the potash fertilizers. Nor is any good effect to be expected from the other phosphatic fertilizers.

Of the nitrogenous fertilizers, calcium cyanamide takes easily the foremost position. The two finely ground forms (" unoiled " and " oiled ") have a considerably better effect than " granular " and " pearl " calcium cyanamide. In contrast to the other nitrogenous fertilizers, the effect is still satisfactory even when the dose is divided. According to Weigert and Weizel's experiments, the remaining nitrogenous fertilizers are arranged in descending order of effect as follows after calcium cyanamide, chloride of ammonia, Chile saltpetre, Leuna saltpetre, sulphate of ammonia, calcium nitrate, urea, nitrogenous calcium phosphate, nitrochalk, and finally the complete manure Nitrophoska, containing calcium.

Of the lime fertilizers, quick lime (CaO) exhibited, as was expected, the greatest efficacy.

In the experiments of Weigert and Weizel the percentage of weeds killed by means of the application of fertilizers during the germination period was very high. The employment of calcium cyanamide reduced the proportion of weeds to 1.4 per cent of the control plants, kainit to 2.2 per cent, 40 per cent potash salt to 13 per cent, chloride of ammonia to 20.3 per cent, and even the little effective complete manure Nitrophoska reduced weeds to 55 per cent of the control plots.

Although these results may have been obtained under particularly favourable circumstances, they point to the important conclusion that the proportion of weeds can be reduced by the application of any commercial fertilizer at the time when the weeds are germinating, and that it can be reduced to complete insignificance through the use of certain fertilizers such as calcium cyanamide and kainit.

On account of possible injury to the germinating crop plants, this method naturally cannot be generalized. Experience of each soil type concerned must first be gathered. In the case of cereals the fertilizer should be applied approximately eight days before the seed is sown or when it germinates, in the case of beet eight days before sowing, for potatoes not until shortly before the last hoeing It is for root crops in particular that the method seems to be gaining in importance (Fig. 14).

Fertilizers for the control of young weeds

This method of control was developed in Germany after the war of 1914-18 ; within the last one and a half decades it has attained wide distribution there and its use is still increasing. The fertilizers employed are restricted almost entirely to calcium cyanamide and kainit, used practically exclusively for cereals, as dicotyledons with few exceptions (peas, vetch, poppies) are injured at the same time as the weeds.

(a) Corrosive fertilizers in winter cereals

The object of this is a selective action upon leaf and soil. The action is selective in that, when the fertilizer is properly applied, the weed is destroyed, but the cereal—on account of the erect position of its leaves, the layer of wax on the leaves and the strong rooting system—is only temporarily injured. The action upon the leaves exercised both by calcium cyanamide and kainit consists of a corrosion or plasmolyzing of the leaf tissue. The effect on the soil is exercised especially by calcium cyanamide, the germinating weed seeds and the rootlets of plants that have already come up being destroyed. Experiments have shown that, in the case of calcium cyanamide, either of the two forms of action alone can lead to complete success.

In using corrosive fertilizers in winter cereals, great care must be taken to avoid injuries which might lead to winter-killing. For this reason, such fertilizers should not be used in winter wheat and winter barley until the third to the fourth leaf has been formed, in the case of the more sensitive rye not until the formation of the fourth to the sixth leaf. The lighter the soil, the weaker are the plants; and the more unreliable the climate, especially as regards cold, the more careful must one be in choosing the time of applying the corrosive and the quantity to be employed. Between the west and east of Germany only, very great differences exist in the possibility of employing this method of weed control.

The time of applying the corrosive fertilizer must be chosen with regard to both cereal and weeds. Considerations in regard to the cereals have already been discussed. As regards the weeds, application should not be made until most of these have already come up. On the other hand, one must not wait too long, as otherwise the weeds will become too old and can no longer be killed. In accordance with the given locality, there is a wide margin of time in which the method may be employed, ranging approximately from three to six weeks after the autumn sowing until the following spring. In choosing the time of dusting, the manurial effect of the fertilizer to be employed must also be taken into consideration.

The weather exercises a decisive influence upon the success of the method, a dependence which is at the same time the greatest weakness of the method. Calcium cyanamide is generally dusted upon dry plants, kainit and the mixture of calcium cyanamide and kainit upon plants moist with dew. In the east of Germany, the fertilizer must not be dusted in frosty weather, nor when there is alternate warmth by day and frost by night, and in particular not before a period of black frost, as the cereal would otherwise suffer too greatly. In the regions of the coast and western Germany, where winters are mild, it is possible to apply the fertilizer even during periods of light frost and to dust rime-covered plants, provided the stands are otherwise vigorous. Even here, however, treatment is dangerous when frosty weather is about to set in. According to studies by A. Flock (**10**), calcium cyanamide has a better effect when atmospheric humidity is greater, kainit when conditions are less humid. The effect of the mixture, however, is to a considerable extent independent of humidity.

The soil must be moist in order that the fertilizer, calcium cyanamide in particular, can be more rapidly converted. Rainfall after dusting is very undesirable.

The longer the rainless period, the better is the effect. Rain not only washes the fertilizer from the leaves, but dilutes the poisonous solution in the soil to the point of ineffectiveness and leaches it.

Knowledge of weather conditions is so important for this means of weed control that some of the German wireless transmission stations broadcast during the critical months special weather forecasts for this purpose (Meyer-Bahlburg, **27**).

The quantity and kind of fertilizer to be employed is chosen according to the nutrient requirements of the crop plants and according to the species and age of the weeds concerned. As a general rule no more is given than the plants require, especially in the case of calcium cyanamide. The worse the growth of weeds, the older the weeds and the more difficult to control the species present, the larger the doses of fertilizers to be applied. As a standard may be taken 1.5 to, at the most, 3.0 dz. calcium cyanamide per hectare (also applicable in two part doses, although with diminished effect), and 4 to 8 dz. of kainit-calcium cyanamide mixture in a ratio of 4 to 6 : 1. The use of pure kainit in winter cereals is generally out of the question, on account of the danger of making the soil muddy and sticky and the risk of cold. The good distribution of the fertilizers is of great importance. Whenever possible manure distributors should be employed. For the application of calcium cyanamide a special dry spray, which may be attached to any manure distributor, is made by Bassum's foundry near Bremen.

The corrosive fertilizers are effective in killing all the important seed-propagated weeds of winter cereals, with the exception of *Alopecurus agrestis*, which suffers little even at a very early stage. Although we already have from practical experience much information concerning the sensitivity of the various species (Makkus **26**, Meyer-Hermann **28**, and many others), yet many gaps in our knowledge still remain. For the last two years my pupil, A. Flock, has been conducting detailed experiments on the sensitivity of the different weed species to various fertilizers, the results of which will be published in 1940. His studies show that some weeds are more susceptible to calcium cyanamide, others to kainit, while the mixture of both fertilizers has a good effect in practically every case. At different growth stages also, the reaction of the plants to the fertilizers is different. Among the more important species, *Apera spica-venti* and *Papaver Rhoeas* are most affected by calcium cyanamide, *Centaurea cyanus*, *Vicia hirsuta*, *Stellaria media*, *Veronica hederifolia* and *Galium aparine* by the mixture. In the case of *Veronica hederifolia* and *Galium aparine*, kainit had almost as good an effect, in the case of *Centaurea cyanus* and *Vicia hirsuta*, the mixture was most successful. For similar details and for an analysis of the many factors influencing the effect of the fertilizers, reference must be made to the above-mentioned work.

In any event, the process is economic on account of its manurial effect, even if in consequence of unfavourable weather conditions the weed-killer action of the fertilizer has been annulled.

(b) Corrosive fertilizers in summer cereals

This manner of using corrosives was already known before its employment in

winter cereals, just described, and has been much practised in Germany from about 1907 onwards. As in the case of winter cereals, here also only kainit and calcium cyanamide and a mixture of the two are used. Unless the application is made very early, action on the leaves of weeds is the aim of treatment. The method can be employed, therefore, only for cereal stands, or even perhaps for legume mixtures shortly after the crop has come up. When there is a bottom growth of clover, however, it must be used only under quite special circumstances (a very close sward of weeds covering the young clover).

This treatment is principally designed for the control of the summer seed-propagated weeds that are by far the most widely distributed and dangerous in Germany, namely, *Raphanus raphanistrum* and *Sinapis arvensis* (Fig. 15). Most of the other seed-propagated weeds are also destroyed, with the exception of those having a heavy layer of wax, such as *Fumaria officinalis*. Root-propagated weeds, on the other hand, suffer temporary injury only. The quantity of corrosive fertilizer employed is chosen in accordance with the species, quantity and age of the weeds concerned, as well as according to weather. As *Raphanus raphanistrum* is more resistant than *Sinapis arvensis*, the quantities must be somewhat increased for the former species. Both weeds are more difficult to eradicate when, in consequence of slow growth (cold, drought), the epidermis has become thick and pubescent. In this case also the doses will require to be increased. The same holds good when the field is very heavily overgrown with weeds and for older weeds. Results will probably be most successful when the weed species referred to have formed two to four leaves. At a later stage treatment very soon becomes ineffective.

The quantities to be employed are, therefore, in the case of calcium cyanamide approximately 1.5 to 3 dz. per hectare, in that of kainit 8 to 16 dz. per hectare, and in that of the mixture 0.6 to 1 dz. calcium cyanamide and 3.5 to 8 dz. kainit per hectare. With kainit the effect is seen within a few hours, while that of calcium cyanamide is visible only after a few days. In this respect the mixture takes an intermediate position. In contrast to the employment of corrosives in the winter, kainit is of greater importance in the treatment of summer crops, because calcium cyanamide doses of any size at a later period and for sensitive crop plants (brewer's barley) have the well-known disadvantages. The mixture of both corrosives is to be highly recommended in this case. As once again uniformity of distribution is of great importance for success, the employment of good manure distributors has been found particularly useful.

As in the case of winter cereals, here also the weather is of decisive importance for success. As action upon the leaf is the primary object, the fertilizers must be used in the morning dew or after light rainfall. In order to be independent of dew-fall, manure drills with a "dew distributor" attached have been designed, for example, that made by the firm of Kuxmann, Bielefeld, but they have not yet been widely adopted. Sunshine after the application is very desirable, as it increases the effect of the fertilizers considerably. Conversely, rain following the treatment the more annuls the effect of the weed-killer, the sooner and the more heavily it falls after treatment. Success is ensured, therefore, only under constant weather conditions.

This unfortunate dependence upon the weather is the principal weakness of the method, which in all other respects is very economic on account of the simultaneous manurial action of the weed-killer. Consequently, when the weather is unreliable preference is generally given to treatment with iron salts and especially copper salts, discussed below, as these take effect considerably more rapidly and are therefore more independent of a subsequent change in the weather.

Corrosive fertilizers on grassland

We are as yet insufficiently informed concerning the action of calcium cyanamide and kainit on the weed growth of hay land and pastures. Here also the employment of corrosives is designed to destroy weeds and to spare the cultivated plants, but as, in addition to the grasses, other sensitive plants are included among the cultivated species of grassland (especially clover and allied species), selective treatment is not so simple as in corn fields.

Treatment may take place in the early spring, before grass growth sets in, and when the weeds are beginning to flower. The first form is that usually employed now. The fertilizers, when used very early (February to March), that is, before the grass and clover begin to grow, are dusted on the moist plants, but later on the dry plants only. Dry and, as far as possible, sunny days should follow. Treatment should not be undertaken when there is frost. The earlier the application is made, the less are the grasses and clovers injured, but it is true that at this period the effect on the germinating weeds also is inadequate. In no case must the grasses be so far developed as to afford a protective cover to the weed rosettes.

In the case of older weeds, the killing is generally far from complete. Considerable weakening of these plants may nevertheless be very useful, if—through suitable manurial treatment—the grasses can at the same time be so encouraged that they completely suppress the enfeebled weeds. When properly employed, therefore, the effect on the germinating weeds is inadequate. Sometimes this is not seen until two or three years later, when the weed seedlings on the untreated control areas have developed into flowering plants. Thus I was able to demonstrate in my own experiments that, although the older rosettes of *Plantago* were not entirely killed, seedlings of the same weed were completely destroyed by the use of kainit.

In addition to this employment in the spring, kainit and calcium cyanamide have also been used successfully in the control of older and even flowering weeds when covered with dew, for example, *Taraxacum officinale, Petasites officinalis, Cardamine pratensis, Primula* and especially *Alectorolophus* spp. It is also possible to use the treatment in hay fields after the first cut has been taken, for controlling late-growing weeds such as *Heracleum sphondylium, Cirsium oleraceum* and *Cirsium rivulare.*

The employment of corrosive fertilizers in summer and midsummer, certainly, is always coupled with a considerable amount of injury to the growth of the herbage, so that it is not advisable in every case.

The quantities used may range, in accordance with circumstances, from 2 to 4 dz. calcium cyanamide per hectare, from 5 to 15 dz. kainit per hectare, and corresponding quantities of the mixture of the two fertilizers.

Action of corrosive fertilizers on crop plants

In the previous sections the effect of kainit and calcium cyanamide on the crop plants has been repeatedly described. To summarize : kainit and calcium cyanamide can be used for the control of already growing weeds only in cereals, and in legume-cereal mixtures shortly after the crop has come up. Injury to cereals, in consequence of the erect position of their leaves, their covering of wax and their strong rooting system, is usually only of a temporary nature. Legumes also, having a heavy coating of wax, suffer at the early stages less severely than the other dicotyledons, all of which are endangered. A greater but generally insufficient power of resistance to corrosives is found in vetch, rape, cabbage, linseed and poppies, of which the two last-named, however, are fairly susceptible to injury from calcium cyanamide.

Care should be taken in the employment of kainit and calcium cyanamide in winter cereals, because of particular risk to these crops during the winter. It may be dangerous, in accordance with the sound condition of the plants and the course of the weather, to apply corrosives to barley before the formation of the third to the fourth leaf, to rye before the formation of the fourth to the sixth leaf, and calcium cyanamide to moist plants. It may also be dangerous to undertake the treatment before or during a period of frost or under extremely changeable temperature conditions (in the spring). A fundamental rule is that, in the use of corrosives, care must be the greater, the weaker the stand of cereals, the more extreme the climate and the lighter the soil. In some cases it is desirable, when the use of corrosives is contemplated, to increase the seeding rate by 5 to 10 per cent.

When clover is sown under summer cereals, corrosives should be used only if the young clover is protected by a close sward of weeds. It is also possible to defer the sowing of clover until after the treatment and after the transformation of the corrosive fertilizer in the soil (rainfall).

According to our research up to the present, corrosives may be employed in maize cultures only before sowing or at a very early stage (shooting to the formation of the first leaf). At a later stage maize, in contrast to the other cereal species, is particularly seriously damaged by kainit. In grassland, as we saw above, the injury of grasses and legumes is the more probable, the later the corrosives are employed.

An article by Weigert and Weizel (**48**) gives information on the effect of other fertilizers applied as a top dressing, although hardly of use as weed-killers. In the main it confirms knowledge obtained from practical experience. Turnips, potatoes, maize and lucerne proved to be especially sensitive, and to a somewhat less degree red clover.

CONTROL MEASURES—SPECIAL CHEMICALS

By " chemical means " of weed control there are understood here those chemicals which serve the special purpose of weed-killers and which have no other manurial value or only an occasional effect as fertilizers. Of these chemical means, there may be distinguished those which are selective and those which are totally destructive. Those with a selective action injure weeds more than cereals, and can therefore be employed in fields of cereals. The others destroy all plant life, and cannot therefore be used when crop plants are present.

Chemicals with selective action

These include heavy metal salts, such as iron sulphate and copper salts, as well as inorganic acids. The use of copper salts may be traced back to an accidental observation of the French vine-grower, Bonnet, who made a report to the Agricultural Association at Rheims on December 12th, 1896, on his success in controlling *Sinapis arvensis* in oats with a 6 per cent solution of copper sulphate. Almost at the same time, in the year 1897, the German Schultz carried out successful experiments at Soest in the control of weeds with copper salts (**39**). The discovery of the value of iron sulphate by the French farmer Martin, of Pont d'Ardres, also took place at this time.

Iron sulphate

Iron sulphate (green vitriol), $FeSO_4.7H_2O$, can be used in solution or as a salt for the control of weeds. For use in solution it is employed in the form of crystals or, more recently, often in the finely crystallized " snow form ". The snow form has the advantage of better solubility. If used as a salt, it is distributed either in the form of powder, but generally as " charlock powder " with 25 to 40 per cent gypsum. Iron sulphate is prepared almost exclusively as a by-product of chemical industries and especially of sheet metal and wire factories. As its price in consequence is comparatively low, it is the cheapest of all the chemical means of control.

To-day iron sulphate is used almost exclusively for the control of weeds in summer cereals, especially *Sinapis arvensis* and *Raphanus raphanistrum*. In accordance with circumstances, 800 litres of a 20 to 30 per cent solution per hectare is applied to the dry plants with special " charlock sprays ". In the case of young, rapidly growing and not too dense weeds, the lower concentration may be used. For older, slowly grown and very dense weed growths, higher concentrations must be employed. This holds good especially for the resistant *Raphanus raphanistrum*. As the salt is effective only in solution, the same quantities of iron sulphate per unit area must be used in warm and dry, windy weather in lower concentrations, but with greater quantities of water, in order that the drying process is not too rapid. Conversely, in conditions of considerable humidity and in cool, still weather, lower quantities of liquid with higher concentrations of the iron sulphate may be employed. The concentration is best controlled by means of a vitriolometer.

Iron sulphate can be kept for a long time when carefully stored. The initial content of ferrous sulphate (up to 57.78 per cent) diminishes in the course of a year by approximately 2 per cent only, that is, a practically insignificant quantity. The crystals weather a little in the air, giving off water, and are covered with a white layer. In damp air, water is absorbed and a brownish layer of basic ferric sulphate or ferric sulphate, $Fe_2(SO_4)_3$, is formed. While slight discolorations, even under long but good storage conditions, are unimportant, greatly decomposed and discoloured iron sulphate has a reduced action and must then be employed in higher concentrations to obtain the same effect.

Just as when corrosives are used, spraying with solutions of iron sulphate is most successful when the weeds have formed the second to the sixth leaf. In

addition to *Sinapis arvensis* and *Raphanus raphanistrum*, most of the other seed-propagated weeds found in summer cereals are killed, but little is yet known concerning the specific susceptibility of the different species. The cells are killed through plasmolysis and destruction of the plasma. The plants dry up with a dark, almost black colour, which is characteristic of the effect of green vitriol.

It may be noted, in addition, that green vitriol can be successfully employed for the destruction of moss in grassland. For this purpose, 15 to 20 per cent solutions in very large quantities (1,800 to 2,000 litres per hectare) are recommended, but the treatment is worthless unless at the same time the actual causes of moss growth are removed and the herbage is invigorated by good manuring.

Clover sown under cereals is less susceptible to solutions of iron sulphate than to corrosives, but when clover sowings are present, the concentrations should not be stronger than 20 to 25 per cent. The same reduced concentrations may be used for weed control in linseed, peas and poppies.

The greatest difficulty in the employment of iron sulphate is that of dissolving the salts in the high concentrations of 20 to 30 per cent. This must be done in special kinds of apparatus, which can be bought but may also be home-made. The formerly feared clogging of the sprays hardly ever occurs to-day, as the salts supplied are much better cleaned and the newer sprays are provided with sieves which may also be attached to the older forms of spray (Lindemuth **25**). A further disadvantage is that, with such high concentrations, considerable quantities of the substance must be carried, in addition to the water of the solution. The soiling of clothes and boots, also, is disagreeable. In the main, however, the iron sulphate solution has a very good effect and its employment is less strictly confined to any given time than that of sprays which can be used only when the dew is on the plants. Certainly it is somewhat more dependent on subsequent weather than are the copper substances yet to be discussed. The greatest advantage of iron sulphate is its cheapness, so that, once the farmer is more or less familiar with its employment, it is readily adopted.

Fürst, on the basis of his wide experience, notes that the water used is also not without importance for the effectiveness of the iron sulphate solution (**12**). He found that, when water containing lime was used, a disturbing formation of flakes took place, which could, however, be eliminated by the addition of a small amount of acid.

The use of iron sulphate in solid form is much less general than that of iron sulphate in solution. It has, in common with the corrosive fertilizer, the disadvantage of being applicable only at certain hours of the day, namely, in dew, but without possessing at the same time the advantage of simultaneous manurial action. The method is chiefly employed where, on small areas, spraying is not worth while, or where it is desired to avoid the use of corrosive fertilizers because the nutrient requirements of the plant have already been covered. In addition to the snow or powder form of iron sulphate applied in quantities of 2 to 3 dz. per hectare, commercial preparations are generally used. Three factories are at present recognized by the German Plant Protection Service for the supply of iron sulphate preparations. Finally, it should be noted that in some cases, certainly rare, the application of iron sulphate may have a manurial effect, for example, in chlorosis of lupins.

Copper salts

Although our first observations on the suitability of copper for weed control were concerned with copper sulphate, this compound has not yet become of any importance as a weed-killer, at all events in Germany. It is rather other salts such as the chlorides, but especially the nitrates and acetates, which have come to the fore. As to the manner in which copper acts, numerous investigations by phytopathologists are available. They have recently been summarized by Daxer (**7**) and supplemented by some findings of his own.

Copper compounds, like iron sulphate, may be used in solution and as dry salts. The form of distribution, however, is of less importance than in the case of iron sulphate. All the copper substances used for weed control in Germany to-day are commercial preparations, of which seven are at present recognized by the Plant Protection Service ; of these, six are used in solution and one (a mixture with iron sulphate) as a dust. Of the solutions, Raphanit, on the market for over twenty-five years (Schering A. G., Berlin N. 65), is the most important.

As regards employment, effect, and dependence of the effect on external conditions, especially weather, the same holds good as has been said in the case of iron sulphate. In comparison with the latter, however, copper sprays have the following advantages :

1. Solutions of much lower concentration are employed (in accordance with the manufacture, 1 to 4 per cent). The cost of transport is thereby reduced not inconsiderably. The preparations are supplied either as highly concentrated solutions in carboys or as readily soluble salts, so that no difficulty is encountered in making the solutions. Clogging does not normally occur.
2. Copper weed-killers have an extraordinarily rapid effect and are, therefore, to a great extent independent of weather conditions. As the effect is complete in a few hours, rain after this time cannot interfere with the success of the treatment.
3. The margin of time within which copper substances may be used is considerably greater than is the case with iron sulphate or even with the corrosives, while copper in low concentrations is completely effective even for the destruction of flowering *Sinapis* and *Raphanus*. The spraying of weeds when in flower, in itself possible, is not done in Germany, for several reasons. At this late stage the weed has already done its worst damage, so that practically nothing but seed formation is hindered by the treatment. Further, the spraying of the flowers is a source of danger to bees, which, as is known, frequently visit the two weeds in question.

Against these marked advantages of copper in comparison with iron sulphate must be placed the disadvantage of its higher price. Nevertheless, it is possible that the use of preparations of copper is rather greater in Germany to-day than that of iron sulphate.

Recently the control of weeds by means of copper has received a new significance. It has been shown that copper can be absorbed by the leaves even when the smallest quantities are sprayed, and that thereby a rapid elimination of the symptoms of copper deficiency can be obtained (Rademacher **33**). Thus in the heathlands of northwestern Germany, where the heathland or reclamation disease produced by copper deficiency occurs, preparations of copper are particularly suitable for use as weed-killers. This is especially true in the very numerous cases where copper

deficiency is slight and, on account of the lack of the actual symptoms, has not been diagnosed. When copper is used in these cases there occurs, independent of the destruction of weeds, an increase in the yield of cereals which was formerly attributed to " stimulation ", but is recognized to-day as a consequence of supplying the trace nutrient element, copper. Where commercial preparations contain copper in the form of nitrate, there is in addition a slight manurial effect produced by the content of 6 per cent nitrogen.

The use of copper in the form of a dust is still less common than in the case of iron salts, as it does not offer any advantage whatever. For this reason the manufacture of Raphanit in the form of a powder for dusting dew-wet stands has been abandoned.

Of all the selective weed-killers, copper has the least injurious effect on a bottom growth of clover ; as a general rule there is no risk in using it when clover is present. Attempts have recently been made in Germany—on the basis of thorough experimentation (Ulbricht **44** and others)—to use copper as a weed-killer in linseed fields also, a fact which indicates a considerable advance in the maintenance of this crop in a clean condition, in itself a difficult matter.

While the corrosive fertilizers, at least calcium cyanamide and the compound of calcium cyanamide and kainit, are used at the present time for the control of weeds in winter cereals, the use of the metal salts hitherto has been of importance principally for summer crops. From experience of its usefulness as a weed-killer, copper sulphate is used now for the spraying and destruction of potato tops in order to prevent the migration of virus into the tubers. Weed-killers containing copper have been used recently in increased concentrations for the deliberate injury of too luxuriant cereal crops in order to prevent lodging (Angermeier **1**).

Inorganic acids as weed-killers

To report on the use of the different acids is a simple matter ; contrary to the practice in France, acids are practically never used as weed-killers in Germany. The reasons for this are various. The transport and handling of the concentrated acids, as well as their dilution, are attended by danger. As the acids attack metal, the implements for compounding and spraying can be constructed solely of material impervious to acid, which is contrary to the efforts now being made in Germany to obtain a uniform spray for all purposes. In France these sprays are made of pitch pine, lead bronze and antimony bronze. Finally, there is a disinclination in Germany to use acids because most soils in the country tend to be acid and whole regions are in any case subject to podsolization.

Sulphuric acid

The degree of dilution depends upon climate or weather and on the size of the weeds. In moist regions and in wet weather higher concentrations are chosen, under dry conditions lower concentrations. The solutions must be sprayed on dry plants in a quantity of 800 to 1,000 litres per hectare. Here also the effect is dependent on the subsequent weather, but its success is felt comparatively quickly.

In calculating the concentrations it should be noted that the concentrated acid may have different degrees of strength, 93 per cent and approximately 75 per cent, described as 66 deg. and 60 deg. Baumé.

Rabatté recommends the following concentrations:

Sinapis arvensis, to 100 litres water, 5 to 6 litres of 65 deg. Baumé.
Raphanus raphanistrum, to 100 litres water, 8 litres of 65 deg. Baumé.
Centaurea Cyanus, Agrostemma githago, Vicia spp., and others, to 100 litres water, 10 litres of 65 deg. Baumé.

Nitric acid

The ordinary commercial forms of nitric acid have a strength of 62 percentage by weight (= 40 deg. Baumé) with a specific gravity of 1.38, but weaker acids are also made. The concentrations that should be employed correspond to those of sulphuric acid, the quantities amount to 800 to 1,200 litres per hectare. The effect is similar to that of sulphuric acid, but the use of nitric acid has the further advantage of manurial action. On the other hand it attacks metals more severely, and is very corrosive and inflammable.

Other acids and acid compounds

In Switzerland, Neuweiler (**31**) has recently carried out experiments with phosphoric acid, and with mixtures of phosphoric acid and the two above-mentioned acids, but no advance has been made thereby on the methods hitherto employed.

Other chemicals with selective action

In the course of time many substances have been tested for their suitability as selective means of controlling weeds, but none has yet been found to compete with those hitherto used and found satisfactory. This is for the present true of the organic substances also, although it has not yet been possible to form a conclusive opinion as to their suitability.

Implements for spraying metal salt solutions

As soon as it was known that it was possible to control weeds by dissolved metal salts, the agricultural implement industry at once brought into the market sprays for the application of these solutions. At first special "charlock sprays" were made, which in the main could be used for this purpose only. To-day efforts are being made to construct universal sprays, which can be used not only for the control of weeds, but also for that of diseases and pests in the field and in horticultural land, as well as for the liming and disinfection of stables, etc. Through the danger of invasion by the Colorado beetle from France, efforts to obtain a universal implement of this nature have received a great stimulus, so that several good patterns are now available in Germany. Sprays suitable for weed control are made in various sizes and patterns by the following firms: Drescher, of Halle on the Saale; Fricke, Bielefeld; C. Platz, Mannheim; and, from 1940, Holder of Metzingen. The largest implements made have a working breadth of 6 to 8 metres and can spray 12 to 15 hectares per day.

While the above-mentioned implements all spray the liquid through nozzles under pressure, the motor potato spray recently brought out by the firm of Rudolf Sack, Leipzig, works on the centrifugal principle. In this invention, originally from Denmark, the liquid runs from the container in a thin stream on to a rapidly revolving disc and is thereby transformed into a spray. The advantage of this construction is its great simplicity, which to a great extent excludes clogging and other interruptions. Its disadvantage is that it can be used only for the treatment of field crops.

The parts of the spray coming into contact with the liquid must be made of a material impervious to acid. For this purpose either steel, treated with a special isolation preparation, or brass is used. For the container oak is found to be suitable.

Costs of treatment with selective weed-killers in Germany

The cost of weed control with selective substances is subject to certain variations, dependent in the first place on the quantity of the preparation purchased and on the cost of freight to the locality concerned. The actual prices for the material, kainit, calcium cyanamide and green vitriol, are relatively constant in Germany at the present time. Commercial preparations of copper, also, are hardly affected by fluctuations in the price of copper. The material costs of treatment per hectare in money and in wheat (according to the mean fixed price of the mean price group W X = 200 RM. per ton in 1939) are as follows:

Table 3.

		RM.		kg. wheat per hectare
Calcium cyanamide	1.5 dz. per hectare	20 to 24	=	100 to 120
Kainit	8 dz. per hectare	18 to 24	=	90 to 120
Mixture of calcium cyanamide and kainit 1 : 6	5.25 dz. per hectare	24 to 26	=	120 to 130
25 per cent green vitriol	800 litres per hectare	8 to 14	=	40 to 70
Copper preparation in prescribed concentration	800 litres per hectare	14 to 20	=	70 to 100

In considering the above-named costs it must be remembered that in kainit and calcium cyanamide the manurial value is included, and, on the other hand, in the case of the sprays the cost of procuring and maintaining spraying apparatus must be added. The cost of labour, also, is not included in the calculation.

Numerous experiments have shown that the methods of control described, even when weed growth is only of medium severity, are of economic importance in Germany. Thereby it must be remembered that the success of the measures employed can seldom be measured by the increased yield of one year, as the prevention of seeding and therewith of weed distribution has a favourable effect on subsequent harvests. The control of weeds, therefore, should not be regarded as a means of increasing yield in a single instance, but as a means of general land improvement.

Chemicals which effect total destruction

The weed-killers used in this group are plant poisons which destroy all plant growth. They cannot, therefore, be employed when crop plants are also present. The forms most generally in use are chlorates and arsenates. Much work has been done in connexion with this form of weed destruction in other countries, North America in particular. I shall confine myself, therefore, to a brief description of its present importance in Germany.

Chlorates

Sodium chlorate is the most important chlorate used as a weed-killer in Germany, but calcium chlorate is also employed.

The mode of action of the chlorates is not yet exactly known. The salt penetrates to the interior of the plant both through the roots and through other parts (leaves), and even small quantities in a short time prove fatal. The weed-killer can therefore be used by way of the soil or can be applied direct to the weeds. In practice, a combination of both methods is generally employed.

Sodium chlorate ($NaClO_3$) is generally supplied in the form of a dry salt, and is used in this form or in solution. It is very readily soluble in water and contains 45 per cent O, 33.3 per cent Cl, and 21.7 per cent Na. As a bearer of oxygen it is liable to ignite inflammable substances with which it comes into contact. This disagreeable property makes certain precautionary measures necessary (the use of implements and containers made of non-inflammable material, never sacks or paper bags, thorough washing of clothing worn during the process, avoidance of smoking and of any contact with fire, storage only where there is no inflammable material). It is not actually a poison for human beings and animals, but naturally it must not be taken in any large quantities. It has no corrosive action on whole skin, but it must not come into contact with open wounds.

Of the totally destructive commercial weed-killers obtainable, sodium chlorate is at present considered to be the best in Germany. With various substances added, it is offered for sale under the greatest variety of names. A pure sodium chlorate has recently been put on the market by the I. G. Farbenindustrie under the name of " Natriumchlorat Streupulver I. G. " (I. G. sodium chlorate dust).

Calcium chlorate, $Ca(ClO_3)_2$, is not yet so commonly used in Germany as sodium chlorate. Its effect, as far as experience yet shows, is approximately as valuable as that of sodium chlorate, but it is somewhat slower in action. A certain corrosive action on metals, exercised by the other chlorates also, can be almost entirely prevented by the addition of 0.1 grm. sodium chromate to one litre calcium chlorate solution (Bechtel, Schütz and Strötzel **2**). The best known commercial preparation of this kind is " Wegda-Lauge ", sold only as a solution by the firm of Feldmühle, Stettin. This lye contains 33 to 34 per cent calcium chlorate and 15 to 20 per cent of the hygroscopic calcium chloride. The last-named addition has the advantage of preventing the chlorate crystals from being blown off the leaves when the lye has dried up, and reduces the danger of fire.

Chlorates are used in two ways :

(1) For weed destruction in localities not under cultivation (railway lines, roadsides, squares, sports grounds, etc.).
(2) For weed destruction in cultivated land.

The first use has become general in Germany. The State Railway especially, private railways and street and road authorities make use of it to a very great extent. Both sodium chlorate and calcium chlorate are employed. The railways apply chlorates in solution by means of special spraying coaches. On an average 30 grm. chlorate per sq. metre railway are used, applied either in one dose in the autumn, or the greater part in the autumn and a smaller dose in the spring. In sloping land it is necessary to spray areas several times with small quantities, to prevent the leaching of the weed-killer.

In streets and roads either solutions or salts are used. For the latter purpose special dusting machines have been constructed by the firm of Schieferstein, Lich, Oberhessen. The employment of an apparatus carried on the back (such as the "Taifun" made by the firm of Carl Platz, Ludwigshafen, Rhine) is also possible. The process is being increasingly used on account of the great saving of labour.

When solutions are used, the concentration is of less importance than the total quantity of chlorate per sq. metre. This, in accordance with soil (see following remarks) and weed growth, should amount to 20 to 30 grm. Generally 2 to 3 per cent solutions are used and 1 litre per sq. metre is sprayed. Both solutions and dust should be applied to damp ground, in order that the salt can penetrate. It is very desirable that the application should be followed by rain. Great care should be taken to prevent the chlorate from being blown to neighbouring cultivated areas, where it would be the source of great damage (Kotte **21**). The action of chlorate is as sharp as a knife (that is, it ceases abruptly at the limit where treatment stops). In the neighbourhood of bushes one may only work as far as the outer reaches of the roots. Trees are in general less endangered, but here also a certain amount of caution should be observed.

The effect continues, in accordance with the nature of the soil and with rainfall, for as long as a year, a subject which we shall discuss at a further point.

Great reserve has been exercised in Germany, in contrast to North America, in the use of chlorates as weed-killers in cultivated land. There are several reasons for this reserve. In the first place chlorates are still relatively expensive. Further, after their employment no cultivated plants can be grown for seven to eight months, which represents a considerable disadvantage under the obligation for the more intensive use of the land in Germany. Finally, importance is attached in this country to holding any measure of this nature in abeyance until it has been thoroughly tested in all directions.

This testing has taken place in a considerable amount of work carried out during the last few years (summarized up to 1935 in an article by Fürst, **13**, and again in work quoted below). Chlorates are now on the market in a form suitable for use by the farmer. Shortage of labour makes the employment of labour-saving methods of control obligatory. It now appears, therefore, as if the use of chlorates had begun to permeate agriculture in Germany.

It is, however, expressly emphasized that this method, like all other chemical means of weed control, is regarded only as an auxiliary measure and must by no means relegate to oblivion the old art of mastering weeds by skilful cultural measures.

The best time for using chlorates in cultivated land is at the end of summer, immediately after harvest, in order that the field can be resown again in the following spring. The earlier the treatment can be carried out, the more certainly will injury to the following crop plants be avoided. No chlorate treatment should be carried out later than the beginning of September. Its action is dependent on sunshine, which is always less in the autumn. In the autumn, also, weeds absorb insufficient chlorate. But most important, when treatment is late there is not enough time for the chlorates to be washed out before the spring.

Before chlorates are used the field should be scaled. After treatment, it is deeply ploughed in the late autumn. There must not be any more ploughing before the seed is sown the next spring, as otherwise chlorate will be brought up into the surface soil.

In cultivated land sodium chlorate is generally employed as a salt. Application must be made on damp ground, if possible during a period of rain, so that the weed-killer can penetrate well into the ground. If necessary, the soil must be made thoroughly wet by artificial means. Distribution may be done by hand or by means of the manure drill, provided the latter has no wooden parts. For better distribution the chlorate can be mixed with three parts of dry sand. Good distribution is important.

The quantities to be employed are chosen according to the weeds to be destroyed, but especially in accordance with the nature of the soil, including the subsoil, and rainfall. The heavier the soil and the lower the rainfall, the less chlorate must be used. In the case of high rainfall and lighter soils with permeable subsoil, on the other hand, one can and must increase the doses, as under these circumstances the chlorates are more readily washed away. For the I. G. sodium chlorate dust the following rules are given :

For heavy clay and loam soils
not more than 100 kg. per hectare when the mean annual rainfall is 500 to 600 mm.
not more than 150 kg. per hectare with an annual rainfall of over 600 mm.
In the case of medium and light soils
not more than 200 kg. per hectare with an annual rainfall of 500 to 600 mm.
not more than 300 kg. per hectare with an annual rainfall of over 600 mm.

The time which must elapse before land treated with chlorates is again sown with seed depends, like the amount of chlorates used, on the soil type (heavy or light), and on the amount of rainfall. In the case of light soil, permeable subsoil and heavy rainfall, this time may be shortened. In general a period of seven to eight months is left between treatment and sowing.

Chlorates are used in Germany exclusively for the eradication of root-propagated weeds, difficult to eradicate. On account of the high price of chlorates the treatment of whole fields can seldom be undertaken, but only that of nests of weeds. Chlorates have proved successful in dealing with the following species : *Equisetum arvense*,

Pteridium aquilinum, Agropyron repens, Molinia coerulea, Aira caespitosa, Calamagrostis epigeios Roth., *Tussilago farfara, Cirsium arvense* and other thistle species, *Petasites officinalis, Cochlearia armoracea* L., *Sambucus Ebulus* L., *Aegopodium podagraria, Ononis spinosa, Convolvulus arvensis, Rumex* spp., *Symphytum officinale* and others. (Braun, **3**, Bucksteeg, **5,** Meyer-Hermann **29,** etc.).

The more vigorous the plant and the deeper its rooting system, the more resistant it is. Of course the more easily killed root-propagated and especially seed-propagated weeds become the first victims to treatment with chlorate. Germination is prevented or the young seedlings are killed back as soon as their roots reach deeper soil layers containing chlorate. Dormant weed seeds, however, are not killed.

While in arable land the total destruction of nests of weeds is generally practicable, in grassland also the destruction of individual weeds can be carried out by means of chlorates. The best method is to apply, in accordance with the size of the tuft, quantities of solution corresponding to 5 to 10 grm. chlorate, preferably after hoeing. When the tuft has disappeared, the bare patches must be resown with grass. For the application of chlorate, an implement commonly employed for the spreading of granular poisons for mice (for example, the Delicia poison spreader) may be used with advantage. Thistle cutters, designed to cut off the thistles and simultaneously to apply chlorate to the roots, do not appear to have proved very successful. Previous mowing and removal are urgently recommended in the case of all weed plants with heavy leaf weight. In the case of many persistent weeds treatment must be repeated a second time, but often enough those plants which still remain alive are so enfeebled that they can be entirely destroyed by cultural methods.

An important point to be noted in the employment of chlorates is the avoidance of damage to crop plants sown subsequently. The first means of attaining this object is the already mentioned period of seven to eight months which should elapse between treatment and sowing.

If during the winter there is unusually little rainfall (less than 200 to 250 mm.) this period is not long enough to render the chlorate innocuous in heavy soil. If it is desired to determine whether there are still injurious remains of chlorate in the soil, this may be done by sowing a plant very susceptible to chlorate, perhaps barley or preferably the sunflower, in earth which has been taken from a depth of 30 cm. in the treated field. The process which has been worked out for *Helianthus annuus Bismarckianus* has been described in detail by Stapp and Bucksteeg (**41**). If one is nevertheless obliged to sow a fresh crop in a treated field in the following spring, a liberal application of good undiluted liquid manure or well fermented farmyard manure, or at the very least a liberal application of commercial fertilizers should be given.

In any case, after chlorate treatment it is well to sow plants which are less susceptible to chlorate, such as rye, oats, maize, vetch mixtures, clover, horse beans, peas, Peluschka peas, *Ornithopus sativus*, potatoes, and grasses, and to avoid further crops sensitive to chlorate. The latter include barley, beet, sunflowers, and— according to my own experience in 1939—hemp also (*Cannabis sativa*).

The use of sodium chlorate has unfavourable effects neither upon soil reaction

nor upon its physical structure (Pfeil **32**). A favourable soil activity is produced through the destruction and decomposition of the roots. According to studies by Stapp and Bucksteeg (**40**), the bacterial organisms of the soil suffer at the most only transitory injury from chlorate in the quantities used for weed destruction.

Arsenical weed-killers

Weed-killers containing arsenic are very much less common than the chlorates. Although in Germany arsenical salts are manufactured in large quantities as by-products of industry, only a few preparations of this nature are sold. Like the chlorates, they are used exclusively for areas free of crop plants ; but their employment is recognized by the German Plant Protection Service only under the proviso that the local sanitary authorities have no objection to their use in places where they might be of danger to human beings, for example children at play.

Other weed-killers

In Germany, as elsewhere, very many substances have been tested from time to time as to their possible use as weed-killers, but as none of these have yet been adopted for use, they may be ignored for the purposes of this review.

D. GOVERNMENT MEASURES, COMMUNITY MEASURES AND THE ORGANIZATION OF WEED DESTRUCTION IN GERMANY

In accordance with German law the land is not left to the private caprice of the individual, but is regarded as precious national property, which the owner or occupier for the time being is under an obligation to husband on behalf of the people. In consequence of this conception, by the Reich Inheritance Law of 1933 every farmer is obliged to keep his land in good order, otherwise he may be deprived of it so far as he personally is concerned, although it remains reserved for his descendants. As excessive weed growth is always a sign of great neglect, the authorities have here a means of taking severe measures against those who thus place themselves beyond the pale.

There are numerous police regulations which require the eradication of certain weeds. According to Braun's summary (**3**), regulations in Prussia are concerned with the following weeds : *Berberis vulgaris*, *Cuscuta* spp., *Solidago serotina*, *Chrysanthemum segetum*, *Senecio vernalis*, *Raphanus raphanistrum*, *Sinapis arvensis*, *Anethum graveolens*, *Cirsium* spp., *Tussilago farfara*, *Petasites hybridus*, *Galinsoga parviflora*, *Orobanche minor*, *Colchicum autumnale*, *Euphorbia cyparissias*, *Avena fatua*, *Taraxacum officinale*, *Alectorolophus* spp., *Convolvulus arvensis*, *Ranunculus* spp., *Chenopodium* and *Atriplex* spp. It must be noted, unfortunately, that these regulations are not entirely complied with, for it is not always possible to eradicate the weeds at the proper time.

It has already been mentioned that the organization for the recognition of seed and regulation of the seed trade has been and still is very beneficial in the suppression of certain weeds.

As experience has proved that the individual cannot be more than partially successful in his efforts to control weeds unless his neighbour, too, is active in the same direction, during the last few years there has been an increase in the organization of community action affecting large regions. Community action of this kind is directed in the first place against weeds such as *Raphanus raphanistrum* and *Sinapis arvensis*, which are easy to control but are at the same time dangerous. It is organized, with some help from the Government, by the Plant Protection Offices of the Regional Farmers' Associations, for example, those of Bavaria, Hessen, Hessen-Nassau and others. It is impossible to go into detail here, but reference is made to an article by Fürst (**14**), which gives a detailed account of the measures taken to control charlock in Bavaria. On the whole, this method of concentrating efforts on a particular point, after previous propaganda and careful detailed organization, has proved so valuable that its use is being continued in Germany.

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G. A. Currie **Australia**

SOME AUSTRALIAN WEED PROBLEMS

INTRODUCTORY SURVEY

Situated between 10° and 40° south latitude, Australia has a range of climates from tropical to temperate, and rainfalls varying from 160 inches a year on the coast of North Queensland to less than five inches a year in the dry heart of Australia. The rainfall varies from summer monsoonal rains in the Northern Territory, through evenly distributed rain in eastern New South Wales, to a winter rainfall in south-western parts of Western Australia.

Australia, therefore, contains suitable climatic habitats for a large proportion of the plant pests of the world, and, indeed, most of the serious Australian weed pests are introduced plants; one or two only (e.g., *Bassia Birchii* F. v. M.) are native.

Australia has not yet developed intensive agriculture in all her arable lands, so that in certain districts continuous production of one crop is still practised. By continuous cropping of wheat, weeds such as wild oat (*Avena fatua*), skeleton weed (*Chondrilla juncea* L.), wild turnip (*Brassica Tournefortii* Gouan.), and hoary cress (*Lepidium draba* L.) assume an importance on wheat land which they would not have in mixed farming.

Pastoral properties are large, and pastures are grazed continuously throughout the year, too often without sufficient attention being paid to changes which occur in the vegetative cover over a period of years. Continuous overgrazing and occasional dry years have opened the pastures and permitted the incursion of weeds and inedible shrubs over large areas of the semi-arid regions of Australia (**1**).

In addition to the weeds which are pests in all parts of the world with similar climatic regions, Australia has special problems arising from peculiar conditions obtaining in her primary industries.

In this paper, a brief outline is given of :—

1. The legislation for the control of weeds.
2. The causes leading up to an extensive programme of research on weed control by the Commonwealth and States jointly.
3. The lines of research being followed in dealing with different weed problems.
4. The more important weeds of Australia, and measures taken to control them.

LEGISLATION FOR WEED CONTROL

For many years the Government of the States of the Commonwealth, possessing, as they do, sovereign rights over their State lands, have had on their statute books acts which attempt to restrict the spread of weeds and to reduce their incidence in areas where they have become serious pests, while the Commonwealth Government,

through its quarantine legislation, has tried to control the importation of weed seeds. The acts are administered by the Departments of Agriculture in New South Wales, South Australia, Western Australia and Tasmania, and by the Lands Department in Victoria and Queensland. Freehold land in Queensland is under the control of the Home Office.

The Victorian act places full responsibility for noxious weed control on a section of the Lands Department. The Minister for Lands has power to declare any plant noxious, and to enforce, through inspectors in each district and through the courts of law, the provisions of the act, which requires that noxious weeds be destroyed on private properties. Failure to comply with the regulations may lead to prosecution by the Crown, or the responsible Department may put men in to destroy the noxious weed and make the cost a charge against the landholder.

In New South Wales, up to 1938, the act was administered by local governing bodies on freehold land, by the Department of Lands on Crown lands, and by officers of the Pasture Protection Boards on stock routes. In 1937 the Government amended its act, and power to declare weeds noxious is now vested in the Minister for Agriculture ; provision is made through local governing bodies for different forms of action to suppress weeds, according to the individual needs of each case.

CAUSES LEADING TO RESEARCH ON WEED CONTROL

The enforcement of the noxious weeds acts in the different States has, without doubt, reduced the rate of spread of some weeds, and has lowered the density of others in certain areas.

A weakness in the organization for weed control in the past, however, has been that, although large sums of money were being spent in paying inspectors to enforce the acts, little was being done to discover the most efficient means of controlling weeds. Land owners instructed to destroy weeds did not always know effective methods to adopt. Those responsible for the administration of the acts were quite aware of this weakness, and, so far as they could, made efforts to remedy it, but they were not organized for research, and pressure of their other duties limited their programme of research. Public demand for the scientific investigation of weed control became so great that, in 1929, the Council for Scientific and Industrial Research started work on certain weeds of national importance :—St. John's wort (*Hypericum perforatum* L.), Noogoora burr (*Xanthium pungens* Waller), ragwort (*Senecio jacobaea* L.). The only previous activity of the Commonwealth in this field was its association with the States of Queensland and New South Wales in the Commonwealth Prickly Pear Board. (See article by A. P. Dodd on pp. 131-43 of this Bulletin.) At first the work was confined almost entirely to the attempt to control certain weeds by means of insects. The great success of this method with prickly pear had made it popular, and hopes ran high that other weeds might be controlled by the same agency. In Victoria, New South Wales and Queensland, State officers co-operated with Federal in this work. In 1934, however, it was decided that work on weed control must be extended into fields other than entomological control, and,

after a preliminary survey (**4**), work on skeleton weed was begun, in collaboration with the officers of the New South Wales Department of Agriculture (**8**).

Co-operative work in Queensland, South Australia and Western Australia started shortly afterwards, and, following the lead of New South Wales, a Committee was set up in each State, under the auspices of the Council of Agriculture*, to initiate and to co-ordinate work on weed control. These Committees consist of certain State officers of the Departments of Agriculture and of Lands, along with representatives of the Council for Scientific and Industrial Research.

RESEARCH ON WEEDS IN AUSTRALIA

The whole field of weeds research being carried on in Australia may be considered under the following headings.

1. Life history studies.
2. Chemical control.
3. Entomological control.
4. Control by pasture management.
5. Control by smothering plants.
6. Control by cultivation and by rotation of crops.

1. Life History Studies

This work is carried on in greenhouses at the laboratories of the Council for Scientific and Industrial Research, at Canberra. Seeds are first submitted to germination tests, and the seedlings are planted out in large pots. Ten plants are harvested every fortnight throughout the growing period until seeds are ripe, data regarding times of flowering and other relevant matters being kept throughout the period. In each harvest the dry weights of roots, stems, leaves and seeds are recorded separately, and, by using non-porous pots in which the water content is kept constant, the amount of water used during the growing periods is calculated. The object of this detailed life history study is to determine at which stage the plant is likely to be most vulnerable to poisoning, how growth is likely to be affected by cultivation at different times of year, and at which stage growth is most rapid and most vulnerable to competition by other plants. The life history studies can be related to all forms of control.

2. Chemical Control

A good deal of experimental work has been carried out in Australia by State officers, in the attempt to control weeds by means of chemicals. These experiments were restricted to testing the weed-killing chemicals already on the market against certain weeds considered to be especially serious, and to finding out the most effective

*The Council of Agriculture consists of the Commonwealth Minister for Commerce and the Ministers for Agriculture of the different States. This body is advised by the Standing Committee on Agriculture, which consists of the Permanent Heads of State Departments of Agriculture, the Federal Department of Commerce, the Commonwealth Health Department, and the Executive Committee of the Council for Scientific and Industrial Research.

amounts to use. The Departments of Lands, in Victoria and Queensland in particular, and the Department of Agriculture of New South Wales, have done much work along these lines, and have accumulated valuable data ; a considerable volume of this work is still in progress.

A critical study of how poisons worked was first undertaken by the Department of Agriculture of Victoria in 1930 (**11**), and when the Council for Scientific and Industrial Research came into the field, in 1934, this was made a major line of research in weed investigations.

Experimental work in the field

Arsenic pentoxide, sodium arsenite, sodium chlorate, Atlacide, common salt, copper sulphate, potassium thiocyanate, borax—all these poisons and others, some of them made up as proprietary mixtures, are being tested against such weeds as skeleton weed, St. John's wort, nutgrass and blackberry. The kind and time of day for spraying, time of year and stage of plant development for most effective spraying, together with best concentration and quantity of poison to be used, and best spreader for use—all are tested in hundredth-acre plots, usually replicated five times in each treatment, the treatments being distributed at random or set out in Latin squares.

The objects of these experiments are to determine the best poison to use in each separate situation, and to discover the cost of application, so that the landholder may be able to decide whether spraying is justified economically in any particular set of circumstances. The effectiveness of the treatments is judged by counts of shoots which recover after spraying and by changes in crop yields which follow spraying.

The early field work by both State Departments and the Council for Scientific and Industrial Research has demonstrated that for certain plants—mainly deep-rooted perennials, such as skeleton weed and *Convolvulus*, and plants forming corms, such as nutgrass and Cape tulip—poison sprays, as usually applied, are ineffective. More intensive studies have been considered necessary in these instances, to discover if a more effective poison or a more effective method of application can be discovered, and this work has been undertaken by the Council for Scientific and Industrial Research. The mechanism of penetration of poisons into the leaves is being studied, in order to find the most effective means of securing entry of toxic materials. Experiments are being carried on to determine the relation of wetters and spreaders to penetration, as well as the optimum environmental conditions for applications of sprays. As poisons, once in the leaves, may be translocated for a longer or shorter distance throughout the aerial part of the plant and the roots, the forces concerned in these movements are being investigated. As the toxicity of different chemicals to plant cells cannot satisfactorily be gauged directly at present other than by field trials, a measure for toxicity is being sought.

The final object of all these studies is to attempt, from a knowledge of the fundamental principles underlying the penetration, translocation and toxicity of sprays, to develop the most efficient possible poisons to apply to deep-rooted perennial plants which are not usually killed by the poisons at present in use.

3. Entomological Control

Since 1902, when Albert Koebele brought insects into Hawaii from Mexico in an effort to control *Lantana* (**13**), keen interest in this form of control has been maintained. The spectacular and immensely valuable control of prickly pear by insects made Australians look forward to the possibility of controlling other weeds by this means.

The principle is merely an application of the fact that biotic agents have a big effect on the density of different species in the vegetation of any area. At one end of the scale, domestic animals have such a great influence on the constituents of the pastures on which they graze that they become the principal agents in determining the botanical character of those pastures. At the other extreme of the same herbivorous animal series are the insects, which, by selective feeding, may influence to a remarkable degree the density of the population of their chosen host plant in competition with the other plants of the habitat ; this is particularly true of insects which are restricted to a single host. Insects sometimes become the limiting factors in determining whether a certain crop can be grown continuously in a certain area : they may also become the limiting factors in determining the density of pest plants in any region.

When it has been decided that an attempt should be made to control a weed by means of insects, the procedure is as follows :—the country of origin of the weed is determined, and insects which feed only on the weed, or on a small number of allied useless plants, are selected for life history studies and for starvation tests on economic plants. If they do not attack any economic plant in the field or under test, a method for sending them to Australia (usually in cool store on board ship or by air) is devised. Here, in quarantine, they are again tested to discover whether they will attack plants of economic value, and if considered safe they are liberated in the field. Experience so far suggests that there is little danger in the introduction of insects which have never been pests in the country of their origin, and which have been known to confine their feeding to one host plant or to a small number of hosts belonging to the same family, even in districts where economic crops are grown.

It is not anticipated that many weeds will be completely eradicated by insects, but it appears reasonable to expect that some weeds may be so hampered in competition with other plants through constant damage by insects that they will succumb to the plant competition rather than directly to the insect damage. When success does attend control by means of insects the costs are non-recurring, a fact which makes it the most attractive method of weed control to the man on the land, who is not called upon to bear the costs of investigation directly.

In Australia, the Division of Economic Entomology of the Council for Scientific and Industrial Research has been responsible for the introduction of insects to control all the weeds being studied, except prickly pear. An arrangement with the States provides that experimental work shall be carried on by this Commonwealth organization, but that, when an insect has become established in any region, the State entomologists shall then be responsible for the distribution of that insect throughout their territory.

4. Control by Pasture Management

In large sections of semi-arid pastures in Australia, in western New South Wales and Queensland and northern parts of South Australia, there appears to be a continuous deterioration of the pasture cover, and consequent incursion of inedible weeds. It is thought that this is due to long-continued over-grazing, particularly by sheep ; although many observations by pastoralists and others support this opinion, there is no precise information on changes which have occurred in the pasture cover to support it.

In the management of any pasture, it is the aim of the man on the land to keep it at the highest production possible throughout the year, and thus to obtain from it the greatest quantity of healthy animal products. A weed problem arises when, through bad management in any of its forms, an aggressive and unproductive plant makes up a large proportion of the plant cover, and so reduces the total production of the pasture. This usually happens through the selective grazing of palatable species, and the rejection of spiny or otherwise unpalatable plants, which thereby gain an advantage. If the process continues unchecked, the plants which are unsuitable as food for stock will slowly assume dominance. This can occur in natural pastures in semi-arid regions, where inedible shrubs often increase to become pests, and in improved pastures in good rainfall districts. An example of this latter condition is found in improved pastures in south-western Victoria, where Cape weed (*Cryptostemma calendulacea*) increases in pastures until it may occupy up to eighty per cent of the available ground cover in over-grazed areas.

Burrs (Noogoora burr, Bathurst burr, etc.) become serious pests before they assume dominance in the ecological sense, because of their attachment to wool, while poison plants (Darling pea, *Euphorbia Drummondi*, Cape tulip, etc.) and plants which cause taint in milk or mutton (stinkwort) also result in loss when present even in small amounts. As Australia is a big wool-producing country, those plants which reduce the quantity and quality of wool are among the most serious weeds of pastures.

If the problem in pasture land were that of killing the weeds only, without ensuring that they were replaced by better plants, procedure would be relatively simple ; but destruction of the weed in dry areas without a continuous replacement by useful plants would be dangerous, because erosion might follow. The weed may be considered as one stage of a retrogressive series in plant succession ; for recovery of the pasture, however, it has to be considered also as the first phase in a progressive series, to be replaced continuously by better plants in an orderly plant succession.

Galvanized burr (*Bassia Birchii*) has been taken as a type in the problem of inedible shrubs, and experiments to determine the role of pasture management in the destruction of the weed and recovery of the pasture are being carried on by research workers of the Division of Plant Industry of the Council for Scientific and Industrial Research, in collaboration with pastoralists, near St. George, Queensland. The plant cover is being kept under continuous observation for a period of years, in order that changes induced by different rates of grazing and by the absence of all grazing may be recorded. The effect of allowing the grasses to mature seed once every few years is also being studied.

The only experiment of similar type previously carried out in Australia was the study of vegetation in saltbush country at Koonamore, South Australia. During the experimental period no regeneration of saltbush in areas where it had once died out took place (**12**).

5. Control by Smothering Plants

Aggressive grasses may, under favourable climatic conditions, choke out weeds. Braken may be killed by Kikuyu grass in this way, in places such as the coastal districts of New South Wales where the climate is suitable. Usually, however, useful species of plants have to be stimulated by high soil fertility to combat weeds. Greenhouse experiments are being conducted to determine the different responses of weeds and certain useful plants (ryegrass) to nutrients, so that manuring to stimulate the useful plants more than the weed may be carried out as a means for control.

Different seeding rates for wheat can affect the growth of weeds, and the optimal rate of seeding for the control of wild turnip is a feature of the programme of research on this weed.

6. Control by Cultural Methods

Routine cultivation of crops has as an objective the control of weeds as well as aeration of the soil, moisture conservation, and the promotion of good tilth. As certain weeds defy control by the ordinary cultivation necessary to prepare the ground for cropping, special attention has to be devoted to them.

In situations such as drive-ways, certain stock routes, and in places where weed infestation is beginning, chemical control may be satisfactory, but for large areas of arable land spraying may be uneconomic, especially where perennials are involved. In such situations, it becomes necessary to devise a system of agriculture which will permit a reasonable return from the land, and at the same time keep the weeds in check.

As a first step, continuous cultivation is tried, to discover the limits of time required to kill out the weed by cultivating at weekly or longer intervals. Usually two seasons are required to bring about eradication by continuous cultivation, but as the withdrawal of land from production during that period may cause a serious loss, a rotation of crops which will reduce this period has to be sought.

In evolving a rotation of crops in a district infested with a serious weed pest, such as nut-grass, the first year may have to be devoted to continuous clean cultivation during the growing season of the weed, followed by a winter hay crop, which should further weaken the weed and lead to a large measure of control. A shorter or longer period of pasture is then followed on the clean land by those crops which are the most remunerative for the district. The weed must be considered as the principal factor limiting production for that district, and all operations planned to keep it in check.

MAJOR WEED PROBLEMS OF AUSTRALIA

In considering the weeds individually, it is convenient to place them in three broad groups :—

weeds of arable land,
weeds of pastures,
weeds of irrigation channels.

Many of the weeds are found in both arable and pasture land, but they are treated here according to the place where they play the major role.

Weeds of Arable Land : Wheat Land

As wheat is one of Australia's most important crops, weeds of wheat lands receive first consideration. No attempt is made to enumerate all the weeds of wheat land, but attention is concentrated on those considered to cause greatest losses to wheat farmers.

SKELETON WEED (*Chondrilla juncea* L.) (Compositae).

(I) Origin and Importance. Skeleton weed is reported to have arrived in Australia during 1914, in chaff brought from the United States of America for drought relief fodder. It is indigenous to the Eastern Mediterranean, the Caucasian region, and eastward, and is not recorded as a serious weed of wheat fields anywhere but in Australia. It causes the greatest losses in wheat areas in the Riverina district of New South Wales, near Wagga, but it is distributed widely through New South Wales and in Northern Victoria. It is a deep-rooted perennial plant, the roots sometimes penetrating eleven feet into the soil.

The rosettes of leaves in spring are succulent and nutritious, and are readily eaten by sheep. The flowering stem is tall and fibrous, is avoided by stock, and interferes with harvesting operations in the grain fields. In wheat fields, it causes serious decrease in grain yields, amounting in some instances to total loss of the crop. The ordinary clean fallow practised in wheat-growing districts does not control the weed, but rather helps to distribute it by spreading pieces of root which give rise to new plants. It spreads also by seed.

(II) Investigations. The particular way in which skeleton weed competes with the grain crop is being investigated ; it is probable that water and available nitrogen are the two factors of most importance. In support of this, work carried on has shown that in 1938, when soil moisture was available in such limited quantity that it was all required for growing the crop, the yield of wheat in experimental plots varied inversely with the amount of skeleton weed present. Moreover, the addition of nitrogenous manures to weed-infested areas has given greater increases in yield in infested than in non-infested areas.

(III) Control. Experimental work to date (**2**) has shown that chemicals will control the plant only when applied in such quantity that the soil becomes sterilized : killing the foliage only has always resulted in regrowth. Lucerne will compete with

skeleton weed and will destroy it in areas suitable to that crop (**16**), and advantage is taken of this fact in devising crop rotations which will control the weed and allow profitable production in the infested area.

Continuous cultivation every two weeks has led to almost complete control in two years, but such cultivation is uneconomic in practice.

(IV) Further Experiments. The objectives are:

(1) Discovering a poison spray which will be translocated deep into the roots of skeleton weed, and so cause destruction of the whole plant.
(2) Determining which pasture plants are most effective in competing with it.
(3) Devising the best rotation of crops for the infested district, in order to control the weed and maintain production.

After three years of continuous experimental work by State Departments of Agriculture and the Council for Scientific and Industrial Research, the position is that no spectacular method of controlling the weed is known, but increasing confidence in the progress of the research has led to a steady recovery of land values in all but the most heavily infested areas.

HOARY CRESS (*Lepidium draba* L.) (Cruciferae).

(I) Importance. This weed is to Victoria what skeleton weed is to New South Wales. It is not, however, confined to that State, but occurs also in South Australia and New South Wales. It is a deep-rooted perennial plant, upon which extensive work has been carried out by Morgan (**11**), of the Victorian Department of Agriculture.

The damage done is mainly the reduction of wheat yields in infested land, and losses are claimed to be increasing yearly. It spreads by seeds and by the removal of pieces of roots from one part of the field to another on cultivation implements. It is distributed throughout the world in climatic regions suitable to its growth, and is considered a pest wherever it grows on arable land.

(II) Control. Continuous cultivation at intervals of fourteen days over a period of two years eradicated the weed in the Victorian experiments, and proper management of lucerne or pasture grasses will keep it under control. Application of a six per cent solution of arsenic pentoxide results in a large measure of control (**8**). One spraying is generally not enough; regrowth appears, so that the spray should be repeated about twelve months after the first application. Hot dry weather for a week before spraying is a prerequisite for success with spray treatment.

SMALLER MORNING GLORY (*Convolvulus arvensis* L.) (Convolvulaceae).

This weed is becoming increasingly important on wheat land in New South Wales, and is assuming considerable importance as a weed of cotton and other crops in south-eastern Queensland and in orchards in the Murrumbidgee Irrigation Area.

(I) CONTROL. In common with the other two weeds just considered, it is a deep-rooted perennial plant, which spreads by means of rhizomes, and is most difficult to eradicate. The ordinary clean fallow prepared for wheat planting does not control it. No special work has been carried out with this weed in Australia, but work on skeleton weed and hoary cress should give information which could be applied to the control of morning glory. If work done in California can be used as a guide, a well-established stand of lucerne is the agent most likely to control it.

BLACK OR WILD OATS (*Avena fatua* L.) (Gramineae).

As the wild oats in a wheat crop ripen their seed just before the wheat, the header-harvester machines help to spread the pest. The seeds germinate over a period; even when one lot of seedlings is killed by cultivation in a fallow, others germinate with the wheat, and, according to the season and the density of the weed plants, do more or less damage to the crop. Careful and timely fallowing of the land, however, greatly facilitates control of this weed.

WILD TURNIP (*Brassica Tournifortii* (Gouan.) (Cruciferae).

(I) IMPORTANCE. Wild turnip is an annual weed, which is mainly a pest of Western Australian wheat fields (7). It was first recorded in 1916, near Merredin, having been brought in by drought relief fodder in 1914, and has been spreading steadily ever since throughout the wheat lands of the West.

(II) EXPERIMENTAL WORK IN PROGRESS. Experiments are in progress to determine whether sulphuric acid or copper sulphate sprays will control the plant economically, and whether heavier seeding of wheat than is practised at present will keep the weed in check during the early period of growth of the crop.

(III) CONTROL. The chief method of control practised is to cultivate fallows to kill seedlings, after early rains have germinated the seeds.

OTHER WEEDS OF WHEAT.

The many other annual seeds, such as saffron thistle, which infest wheat fields, may be considered to be indicators of poor husbandry rather than non-eradicable pests.

Weeds of Arable land: Crops other than Wheat:

NUT GRASS (*Cyperus rotundus* L.) (Cyperaceae).

(I) IMPORTANCE. This weed is responsible for losses in maize, potatoes, sugar-cane, and other crops, in the north-east of New South Wales and in Queensland.

Its growing period is during the summer months. It is a perennial plant, spreading mainly by vegetative growth in arable land, by normal cultivation. The underground rhizomes produce corms and shoots at intervals, and these corms each take up a separate existence from the parent plant when the rhizome linking them

dies. As many as seventy-six new corms have been produced in a single season from a single parent corm, during life history studies with the weed in Canberra. In potato crops in infested districts, some tubers are found to contain corms of nut-grass ; potatoes are therefore capable of spreading the pest to new areas.

In heavily infested maize fields, nut-grass grows very rapidly in summer after the crop has been sown ; when the maize germinates, there is already a green sward of nut-grass shoots to compete with and stifle the young plants, leading to a decreased yield of grain.

(II) Control. Experiments at Lawes, Queensland, have shown that cultivation of the ground at not less than three-weekly intervals during two growing seasons will reduce the nut-grass to negligible proportions. Corms should be turned up to the surface with the cultivation, so that they are dried out and killed. No chemical treatment short of soil sterilization has been effective in controlling the nut-grass.

Experiments in progress are designed to discover a rotation of crops, with one summer season's continuous clean fallow, cultivated every three weeks, as a feature. A suitable rotation would, at the same time, control the weed and allow profitable production from the soil.

(III) Insect Control. Control by means of insects has been considered, and quarantine experiments are in progress with nut-grass insects obtained from Hawaii, but there does not appear to be much likelihood that they will be liberated in Australia. The matter is complicated by the fact that many acres of grazing land in low-lying areas of the lower rainfall zones of Queensland and northern New South Wales contain certain other species of *Cyperus* as their chief grazing plant. It is feared that insects which attack the pest species of *Cyperus* in the agricultural areas might attack also the useful species in the pastoral country.

MINT WEED (*Salvia reflexa* Horn.) (Labiatae).

(I) Importance. This plant, an aggressive annual on the Darling Downs, Queensland, is poisonous to hungry stock unaccustomed to it (**14**). It grows most luxuriantly on black soils, and very quickly assumes dominance in any area which has been overstocked. In wheat fields, it is usually over-topped and suppressed by the wheat, if the season is not adverse to the development of that crop. It has spread over many thousands of acres of country, and is still spreading.

(II) Control. It is easily killed by poison sprays, but the problem is to establish useful plants in its place on over-grazed stock routes and native pastures. Experiments are in progress, by the Queensland State Department of Agriculture and Stock and the Council for Scientific and Industrial Research jointly, to determine the best means of controlling the weed on arable lands, on grazing lands, and on stock routes. The experiments are of three kinds :—(1) exclosures, to discover whether the exclusion of grazing animals from an area will lead to the recovery of useful perennial plants which may compete with and replace mint weed ; (2)

testing chemicals to find the cheapest and most effective for destroying the weeds; and (3) attempting control by cultivation.

Weeds of grazing lands:

NOOGOORA BURR (*Xanthium pungens* Waller) (Compositae).

(I) Importance. This strong-growing annual has become established in sheep country, especially in river valleys and in areas subject to frequent flooding, over the whole of Queensland, and in New South Wales as far south as Sydney on the coast. It was first introduced into Queensland in cotton seed about the eighteen-fifties, probably from America, but possibly from India. It causes heavy loss to the wool industry through the ripe burrs sticking to the fleece; these can be removed only by selective carbonization of vegetable matter in the wool by the action of sulphuric acid.

(II) Control. It is possible, but costly, to control burrs by cutting down the plants in the seedling stage. This is economically permissible only on rich alluvial flats. Chemicals will kill the plants easily, owing to the large expanse of leaf and the shallow rooting habit, but spraying also is uneconomic except in good country well supplied with water. The plants are often found scattered by sheep over huge tracts of country, where cutting or spraying would be too costly to apply.

(III) Insect Control. In collaboration with the Prickly Pear Board, the Council for Scientific and Industrial Research is introducing insect enemies of the burr from America, in the attempt to control it. A rich fauna of insects has been found attacking the cockle-burrs in North America; insects from Texas and Southern California are being sent to Australia, because the climate of these regions is fairly similar to that of the burr-infested areas of Queensland. One difficulty confronting investigators is that many insects attacking cockle-burrs will also attack sunflower and Jerusalem artichoke; this refers particularly to insects living in the stems and root crowns. Although these two plants are not of great economic importance in Australia, the policy is so far to liberate only those insects which are confined in their feeding to the genus *Xanthium*.

Insects which attack the seeds, and others which kill the plants by burrowing in stem and root, have been introduced into Australia, but so far only one, *Euaresta aequalis* Loew., a seed fly, has been liberated in the field.

BATHURST BURR (*Xanthium spinosum* L.) (Compositae).

(I) Importance and Distribution. Bathurst burr is similar in noxious characters to Noogoora burr, but has smaller burrs; its distribution lies in more southerly areas than Noogoora burr. It is most common in New South Wales, but is also present in Northern Victoria and in Southern and Central Queensland.

(II) Control. No extensive experiments for the control of this weed have

been attempted, but it is of interest to note that a small seed fly, *Camaromyia bullans* Wied. (**9**) first discovered in Central New South Wales and apparently accidentally introduced into the country, is common in the burrs, and there is little doubt that it causes appreciable reduction in the density of the burrs throughout the range of the plant.

Experiments will be carried out later, to discover how to manage natural pastures in order that burrs will be excluded from the sward.

ST. JOHN'S WORT (*Hypericum perforatum* L.) (Guttiferae).

(I) Importance. This fibrous-rooted perennial of European origin grows in winter to form a rosette of procumbent stems, and sends up erect flowering shoots in early summer. In well-drained hill lands in winter rainfall areas in Victoria and New South Wales, the pest has taken possession of low-grade grazing country, and some areas of fairly good natural pasture. In one area it is also a pest of wheat land ; wheat harvested on infected land may not find a sale, because of the danger that the weed seed may be carried from one part of the country to another.

Sheep or cattle grazing on the weed develop a photosensitivity in the skin, which is due to the presence of the substance " hypericin " in the leaves. Wool may be shed, the feet and muzzles of the animals become highly irritable to light and to water, and white patches on cattle may break out into sores. Sheep can be killed (**17**) by feeding continuously on the weed, and stock develop a depraved taste for it.

(II) Control. As improved pastures extend, St. John's wort is kept in control by good stands of grass and clover. In the Tumbarumba district of New South Wales, experiments are indicating already that a pasture laid down to ryegrass and white clover or subterranean clover, and well top-dressed with superphosphate, will control the weed.

Both arsenical poisons and chlorate in 10 per cent solutions have been used to kill the aerial portions of the weed, but, owing to the great wealth of seeds in the ground, seedlings appear on the areas, and many plants shoot again, the roots not having been killed. The most effective control by chemical means so far discovered has been in use for many years by the Victorian Lands Department. Crude common salt is scattered dry on the infested ground in quantities from 1 to 10 or more tons per acre, according to the density of infestation. The salt kills the plants and prevents seedling growth for a number of years ; any plant missed, or any seedling appearing later, is " spotted " with salt. The salting also has the effect of encouraging sweet grasses, which appear the year after the salt has been applied.

(III) Insect Control. Attempts to control this plant by means of insects have been carried on for ten years. Insects have been brought from England to Australia, and have been liberated on St. John's wort, but in each case have failed to survive (**3**) (**5**).

A field station has been established in the south of France, where the climate is similar in type to that of Victoria, experience having shown that the insects feeding

on St. John's wort there belong to different species from those in England. This work is still in progress, and will be continued until certain insects which damage the St. John's wort in southern France have been tried in Australia. Insect control, if successful, would be the only possible satisfactory solution in poor grazing land, where the cost of poison is prohibitive, and where sowing of improved pastures is not yet considered to be economically sound.

(IV) Control by Afforestation. In certain areas, the Forestry Commissions have taken over heavily-infested land, and have planted pines. The forests of pines serve to utilize the land, and to reduce the incidence of St. John's wort under their canopy, but fire breaks and waste places in the afforested zone still carry the weed. Forests may utilize the land otherwise wasted, but in suitable areas pastures would be preferable, and the forests cannot stop the spread of the weed.

GALVANIZED BURR (*Bassia Birchii* F. v. M.) (Chenopodiaceae).

(I) Importance. Galvanized burr is a spiny shrub, about eighteen inches high, which is native to the drier inland areas of Australia (15 inches rainfall, and under), and which has spread in the last two decades over natural pastures in the 20 to 30 inch rainfall regions. It is thought that by the continuous grazing of sheep, especially in dry years, the natural pastures have become open to such invaders as *Bassia*, and that this is the primary cause of spread. *Bassia Birchii* is an early invader of bare areas, a prolific seeder which spreads readily, both by branches carrying seeds which adhere to the wool of sheep, and by limbs breaking off and rolling in front of the wind like the "roly poly". Each bush lives from three to five years, but may be readily killed by drought. It is shallow-rooted, and in the tough spiny stage is not much eaten by sheep, although the young growing tips, when they appear after rain, are eaten by sheep.

(II) Experiments for Control by Pasture Management. The heavy black soils of the Mitchell Grass (*Astrebla* spp.) Plains are free from the burr, which is confined to the sandy soils, on which it serves a useful purpose as a soil-binder in areas denuded of other vegetation by overgrazing. As merely to kill the *Bassia* plants there would be worse than useless, experiments aim at continuously replacing them by better perennials, mainly grasses, by natural regeneration, in the absence of heavy grazing. With this in view, the Council for Scientific and Industrial Research has set out a large-scale experiment in heavily infested country near St. George, Queensland, in a rainfall zone of 22 to 24 inches per annum. The experimental area is divided into sections, one of which is grazed at half the rate common in the district, another grazed rapidly each time the grass stand is about 8 inches high, another closed to grazing to allow the principal grasses to seed, and another closed to all grazing.

Fixed quadrats have been pegged out on all areas for continuous observation, photographic records are kept of the vegetation on these fixed quadrats, and techniques have been developed for proper random sampling on the different treatments, so that changes in the vegetation can be gauged and correlated.

It is hoped that a reduction of the grazing rate will lead to a gradual recovery of the more useful elements of the natural pastures and to a disappearance of the *Bassia*. Certain " enclosures ", in which no grazing by any animals is permitted, already show signs that *Bassia* may be eliminated in competition with other perennials when the latter are given a good chance to develop free from grazing.

CAPE TULIP (*Homeria collina* Vent. and *Homeria collina* var. *aurantiaca* Sweet) (Liliaceae).

(I) IMPORTANCE. The Cape tulips, of South African origin, are becoming increasingly more serious weeds in South Australia, Victoria and Western Australia, in winter rainfall regions. The areas infested are small compared with areas infested with the other weeds treated above, but the tulips are poisonous to stock unaccustomed to them, and cases are on record of horses being poisoned by hay which contained dried Cape tulip. Sheep will not graze in areas where the Cape tulip is dense. There are two species in Australia, both perennial, one spreading by underground bulbs and sparingly by seeds, and the other by aerial bulbils.

(II) CONTROL. Experiments in South Australia have shown that single applications of poisonous sprays applied to the leaves are ineffective in killing the bulbs. In areas where wheat can be grown, the bulbs can be eradicated by cultivation; after the ground is clean, pastures may safely be established. Improved pastures, consisting of such species as *Phalaris tuberosa* and subterranean clover, can be established even without previous cropping, where the Cape tulip infests the soil (**15**), but experiments have not yet progressed far enough to show whether the weed will be killed by the competition of the pasture plants.

(III) PROBLEM ON ROUGH LAND. In places where implements of cultivation cannot be used, no means of control have been found. Experiments in progress are designed to discover when the Cape tulip is most vulnerable to attack by poison sprays, and then to find the most efficient and cheapest poison which may be used to kill the weed, by a series of applications after each regrowth.

LANTANA (*Lantana camera* L.) (Verbenaceae).

(I) IMPORTANCE. *Lantana* is a shrub occurring extensively in the tropical and subtropical coast of Eastern Australia, from Cape York to Sydney. It is a pest of grazing lands and young forest plantations, and is an unwelcome invader following bushfires in the rain forests of Northern Queensland. It is said to cause a disease called " pink-nose " in cattle, and to taint the milk of dairy cows.

(II) CONTROL. Control is effected in arable land by cutting and burning the bushes, but elsewhere the pest is still spreading.

(III) INSECT CONTROL. In 1936, the lantana bug, *Teleonemia scrupulosa* Stal. (**6**) was introduced into Australia from Fiji by the Council for Scientific and

Industrial Research, and was liberated in several areas in Queensland and Northern New South Wales by the State Departments of Agriculture. In most places little or no progress has so far been made by the bugs, but near Atherton, Queensland, the bugs appeared in the summer of 1938/39 in vast numbers on about twenty-four acres of lantana, and in May, 1939, had defoliated many bushes and had killed back some of the branches up to two feet. It is not anticipated that the bugs will completely destroy lantana bushes by a single onslaught, as regrowth occurs almost invariably after the leaves have been shed. Continuous defoliation of bushes may, however, allow competing vegetation to overgrow the lantana, and possibly to smother it.

BLACKBERRY (*Rubus fruticosus* L.), SWEET BRIAR (*Rosa rubiginosa* L.), AND BRACKEN (*Pteridium aquilinum* L.).

(I) Importance and Control. These are all occasional pests in pastures in the winter rainfall districts, and cutting and poisoning methods of control are being tried. Generally speaking, only neglected pastures become seriously affected ; the cost of control is justified if land values in infested districts increase sufficiently to permit areas being laid down to improved pastures.

Weeds of Irrigation Channels

Typha spp. (Typhaceae).

(I) Importance. In the Murrumbidgee Irrigation Areas at Griffith and Leeton, and in Victoria, species of bulrush—*T. Muelleri* and *T. angustifolia* var. *Brownii* (**10**)—have taken possession of many of the unlined supply channels and drains. As the *Typha* grows in channels up to a depth of about 4 feet only, the deep main canals are free, except near the edge. Once established, the *Typha* causes silting, and then spreads upstream by rhizomes in the silt which it continually causes to settle. So serious had the pest become by 1935, that water could not be carried along some of the channels to supply the requisite quantity to irrigation farmers.

(II) Control. Experiments to eradicate *Typha* with various chemicals were unsuccessful in Australia, but cutting treatments, combined with subsequent raising of the water-level in channels, have cleared hundreds of miles of channels. A special horse-drawn cutter, which severs the bulrush stems in the sludge at the bottom of the channels, has been invented by engineers of the Irrigation Commission. When the plant shoots again, the young shoot will die back if it has to pass through deep water to the surface. It appears that the leaves are the chief agents for the supply of oxygen to the rhizomes under water ; thus, if they are unable to obtain air for some time after the cutting, the food reserves ferment, leading to the death of the plant. The seedlings develop in fine silt in shallow water, mainly during hot weather, and the channel patrols have been taught to discover and clear up these breeding spots. Now that the cutting treatment, followed by channel patrol, has been adopted by the officers of the Irrigation Commission, the *Typha* can be controlled where it is considered necessary.

FIG. 1.

FIG. 2.

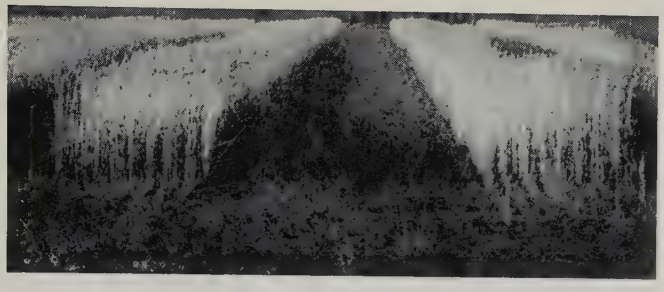

FIG. 3. FIG. 4.

FIG. 1.—Nut-grass, *Cyperus rotundus*, growing among young maize, Queensland.
FIG. 2.—Skeleton weed, *Chondrilla juncea*, growing between strips of wheat, Wagga, New South Wales.
FIG. 3.—Lantana plant in pot (normal).
FIG. 4.—Lantana plant in pot, damaged by lantana bug, *Teleonemia scrupulosa*.

Fig. 5.

Fig. 6.

Fig. 7. Fig. 8.

Fig. 5.—Ragwort (*Senecio jacobaea*) leaves damaged by caterpillars of cinnabar moth, *Tyria jacobaeae*.
Fig. 6.—Galvanized burr, *Bassia Birchii*, growing on overgrazed natural pastures, St. George, Queensland.
Fig. 7.—Weed studies in pots. Greenhouse of Council for Scientific and Industrial Research, Canberra.
Fig. 8.—[illegible] choking supply channel, Murrumbidgee Irrigation Area, New South Wales.

GIANT WATER REED (*Phragmites communis* L.) (Gramineae).

In certain channels, especially in Victoria, *Phragmites* has become a pest. In some instances, it chokes the channel; in others, when the channels have been lined with concrete, it prises up slabs of concrete which have cracked, and so allows water to escape from the channel. Sometimes *Phragmites* spreads from the channel into adjoining orchards and fields. As experiments for the control of this plant have just been started, no results are yet available.

CONCLUSION

Australia has weed problems of great economic importance, most of them caused by weeds introduced from abroad, a few by native plants.

Public bodies and land-owners are keenly aware of the loss caused by weeds, and are pressing for further work to be done to solve weed problems.

Departments of Agriculture and Departments of Lands of the various States assist land-holders by identifying weeds, by giving information about their control and by carrying out the provisions of the Noxious Weeds Acts.

In addition, research into the best means of controlling weeds is being carried on by the State authorities, and by the Council for Scientific and Industrial Research. In the past, the volume of such work had been inadequate to meet the needs of men on the land, but, with the increased attention being given to weeds in Australia, as in other countries, during recent years, research is approaching the stage when it will be commensurate with the economic importance of the problems involved.

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Alan P. Dodd **Australia**

THE BIOLOGICAL CONTROL OF PRICKLY-PEAR IN AUSTRALIA

The destruction of the prickly-pears, *Opuntia inermis* and *O. stricta*, in Australia by the Argentine moth-borer, *Cactoblastis cactorum*, is without doubt the most outstanding example of the control of a weed pest through the agency of insect attack.

SURVEY OF THE PROBLEM

The problem of prickly-pear in Australia can be stated briefly as that of a vigorous, rapidly-spreading weed occupying many millions of acres of grazing land, where, in general, mechanical and chemical methods of eradication were impracticable since the cost of treatment was greater than the value of the land.

Prickly-pears are members of the genus *Opuntia* in the Cactaceae, a plant family indigenous to North and South America. Many species have become firmly established in various parts of the world. The date of introduction into Australia of the various forms is unknown in most cases. However, it is certain that the first prickly-pear was imported with the first colonists in 1788; the species was probably *O. vulgaris* Miller (= *O. monacantha* Haw.), a native of Brazil. The two closely related species, *O. inermis* and *O. stricta*, assumed the dimensions of major pests, while other forms became noxious weeds in certain parts of the country. The several pests species are :—

Major Pests : *Opuntia inermis* DC., a native of the Gulf Coast of the United States from Texas to Florida. The common pest pear of Queensland and New South Wales.
O. stricta Haw., a native of Florida and the West Indies. The spiny pest of Central Queensland, growing either in pure stands or intermingled with *O. inermis*.

Lesser Pests : *O. vulgaris* Miller, a native of Brazil and the Argentine. Established in all States of the Commonwealth, usually in the form of overgrown hedges; it became a definite minor pest in one district in North Queensland.
O. tomentosa Salm-Dyck, a native of Mexico. The velvety tree-pear of Central Queensland, where it grows in dense " scrubs," aggregating many thousands of acres.
O. streptacantha Lem., a native of Mexico. The white-spined tree-pear, distributed over many square miles in Central Queensland.
O. aurantiaca Lind., a native of Uruguay and the Argentine. The tiger-pear of South Queensland and New South Wales; established in a great many areas varying in extent from a few to several thousand acres. It spreads rapidly and is extremely difficult to eradicate by chemical or mechanical methods, even at very great cost.

Several other species of *Opuntia* escaped from cultivation but hardly assumed the proportions of noxious weeds. This article will deal mainly with the two major pests. The efforts to control the other species of *Opuntia* weeds will be stated briefly.

Opuntia inermis was introduced prior to 1839, the earliest definite record of its existence in Australia. With the opening up of the country for grazing, it was planted in 1850 to 1875 for hedge purposes, or was grown as a potential fodder plant at many points in Queensland and New South Wales. These points later became the centres from which this remarkable plant invasion extended. *O. stricta* was probably imported about 1860; its establishment at various places and its later extension followed the same sequence as in the case of *O. inermis*.

From 1900 onward, the spread of prickly-pear was rapid. The peak of the invasion was considered to be reached in 1925 when 60,000,000 acres were affected and when the rate of increase was estimated at 1,000,000 acres annually; about five-sixths of the occupied area was in Queensland, the remaining one-sixth in New South Wales. Of the 60,000,000 acres, approximately one-half was occupied by dense prickly-pear, growing to a height of 3 to 5 feet, and completely covering the ground to the exclusion of all grass and herbage. The other 30,000,000 acres were occupied by a more scattered infestation, varying in density, and by fringing lands in which seedlings occurred. An area of very scattered pear often became a dense mass within three to four years. Dense pear was estimated to contain in bulk 500 to 800 tons per acre.

The infested country extended from the latitude of Mackay in the north to the neighbourhood of Sydney, a distance of about 1,000 miles, and comprised the sub-coastal and mid-inland belt commencing 50 to 100 miles from the coast and extending for a further 150 to 300 miles inland. This tract possesses an annual rainfall of from 20 to 30 inches and constitutes good sheep and cattle grazing land, some of it the best for this purpose in the two States, while large areas adjacent to railway lines are suitable for dairying and the growing of crops such as maize, wheat and cotton. The value of the land, before it could be improved for production purposes, varied generally between 5s. and 30s. per acre. Herein lay the great problem of eradication by mechanical and chemical means, for under the most practicable methods, dense prickly-pear could not be destroyed for less than £10 an acre, an outlay at least several times as great as the value of the land. Mechanical methods, such as digging out, stacking and burning—ploughs, tractors and crushing machines could not be used owing to the fact that the infested country was more or less heavily covered with trees,—were largely superseded, after investigation of the most suitable and economical treatment, by chemical methods. Arsenic formed the basis of virtually all "pear-poisons," usually in the form of arsenic pentoxide. Poisoning or digging out the plants was practised chiefly among the scattered infestations. The periodical, usually annual, cost of checking the invasion of properties was, however, too great a financial load, in addition to other expenditure, for many landowners. Hence, year by year, more land became unoccupied and holdings and homesteads deserted.

THE ORGANIZATION OF THE BOARD

Biological control was suggested many years before the commencement of investigations. In 1912, the Queensland Government appointed a Prickly-Pear

Travelling Commission which, after visiting many countries where prickly-pears were indigenous or had become established, recommended the introduction of insect and disease agencies from America. In 1920, the Governments of the Commonwealth, New South Wales and Queensland agreed to co-operate on biological control investigations, and the Commonwealth Prickly-Pear Board was formed. The Board has been financed by contributions from the three Governments aforesaid. It was originally appointed for a period of five years ; its tenure of office has been extended from time to time and the present term expired on May 31, 1939.

The Board was appointed for the purpose of attempting to combat prickly-pear by means of the plant's natural enemies. It has not been concerned with other phases of control, nor with policies dealing with the administration of prickly-pear lands. These functions are carried out in Queensland and New South Wales by State departmental organizations, the Prickly-Pear Land Commission in Queensland and the Prickly-Pear Destruction Commission in New South Wales. These two bodies have co-operated with the Board in the utilization and distribution of prickly-pear insects established by the Board in Australia.

The investigation has concentrated on the insect enemies of prickly-pear. The possibility of using plant diseases for the control of prickly-pear was given considerable attention in the earlier years of the work, but a survey of the knowledge gained in the investigation indicated that the introduction of fungal and bacterial diseases of the plant did not offer promise of success ; furthermore, many of the diseases of prickly-pear occurring in America were already established in Australia.

The policy of the Board comprised :—

(*a*) the investigation of all insects attacking Cactaceae throughout North and South America ;
(*b*) the study of the life-history and habits of these insects ;
(*c*) the selection of the insects of greater potential value from the aspect of prickly-pear control ;
(*d*) the study of the host restriction of the selected insects, including starvation tests on plants of economic importance, first in America, and if these gave favourable results, later in Australia ;
(*e*) the collection in America of stocks of the selected insects and their despatch to Australia ;
(*f*) the acclimatization in Australia of the insects imported from America ;
(*g*) the large scale rearing of successfully acclimatized insects considered to be of potential value, their establishment in the field, and later their mass distribution.

Work in America

Entomologists were despatched to America before the end of 1920, and investigations were continuous until 1937 either in North and South America or in both continents simultaneously. The greatest attention was given to the United States, Mexico and the Argentine. A field station for the study of prickly-pear insects was maintained in the United States from 1921 until 1933, in the Argentine from

1931 to 1937, and in Mexico for intermittent periods totalling four years between 1926 and 1935. In addition to the major operations, investigations were carried out in Bermuda, the larger islands of the West Indies, Honduras, Guatemala, Nicaragua, Colombia, Venezuela, Brazil, Paraguay, Uruguay, Chile, Peru and Ecuador, in fact, in virtually every country where prickly-pears are known to be indigenous.

Approximately 150 different kinds of insects restricted or apparently restricted to cactus host plants were discovered. Many of the insects proved to be new species. It was established that the family Cactaceae possesses a definite insect fauna, and that genera and even groups of genera are confined to these plants. Very few cactus insects feed on other plants. Similarly, few insects, even polyphagous forms, attacking other plants ever turn their attention to the Cactaceae.

The life-cycle and habits of many of the insects have been studied intensively, both in the field and under cage conditions. Between fifty and sixty different species have been forwarded to Australia ; many forms were collected and shipped in large quantities over a period of several years. The total number of all insects despatched to Australia amounts to several hundred thousands.

The Australian Organization

The headquarters of the Board is the Laboratory at Sherwood, a suburb of Brisbane. Sherwood acts as the receiving, quarantine and acclimatizing centre ; here, too, the starvation tests on economic plants have been carried out.

Field stations were established in the heart of the prickly-pear country, one each in Central Queensland, Western Queensland, South-west Queensland, North-west New South Wales, and the Hunter Valley, New South Wales. The stations in Western Queensland and North-west New South Wales have now been closed but the others are still operating.

These centres were equipped with hundreds of wire gauze and cloth outdoor cages for the breeding of the insects in large numbers. They have acted as the distributional points, and as convenient locations for surveying the progress of events in the field. It should be remarked that liberations were made with Australian reared stocks. The insects imported from America were used for acclimatizing purposes and were not released directly into the field.

THE HOST RESTRICTION QUESTION

It has been a fundamental policy of the Board that all insects introduced into Australia must be those restricted to cactus plants. This policy has been carried into effect by studying the host relations of each insect in the field in America, by investigating its possible presence on other plants (particularly those of economic value) in the vicinity of infested prickly-pear, and by seeking information from scientific sources concerning host relations of the insect and its allies.

The second part of this policy has been the conducting of feeding tests on plants other than cacti, with the object of ascertaining whether the insect could complete its life-cycle on some other plant, or whether, although unable to breed on non-cactus hosts, its feeding in the larval or adult stage on some plant or plants of econ-

omic value might be of such a nature that its introduction into Australia would be inadvisable. The tests were of the starvation type, that is, the insect was not given the option of feeding on anything other than the selected plant. Each kind of insect was tested on a large variety of plants of economic importance, including fruits and vegetables, cereal and other crops such as cotton and tobacco, and general timber and shade trees.

Series of tests against each plant were conducted in America, and if these proved favourable, further experiments were carried out under quarantine conditions in Australia. Frequently, the work with one species was continued for two or three seasons. Many hundreds, even thousands, of larvae, and of adults in the case of Coleoptera, of each species were used in the tests.

Starvation tests under conditions of close confinement may be considered as artificial. The results have fully justified the policy. With no other food available most kinds of insects attempted to feed on the supplied plants. Thus, tunnelling larvae would bore, or try to enter the stems or fruit, and adult beetles would gnaw the foliage, stems, etc. Such attempts were usually unsuccessful and the insects died within a few days. In some cases, they lived longer and appeared to derive some degree of nourishment from the feeding attempts, but were unable to continue and complete development.

In two or three instances, however, prickly-pear insects were able to complete their life-cycle from egg to adult on some plant or plants of economic value, although all evidence showed that they did not do so under natural conditions. These insects were immediately rejected from further consideration.

The data from all observations and enquiries and from the tests were carefully considered and, if deemed satisfactory, the evidence was presented to the Commonwealth Quarantine authorities and permission sought for the liberation of the insect in question. It might be stated that no cactus insect released in Australia is known to have become a pest of other plants.

CONTROL OF THE MAJOR PEST PEARS

Insects Established in Australia

Of the many kinds of insects brought into Australia, some could not be established after continued introductions and investigations. Others were discarded as being of little potential value in the campaign. Those successfully acclimatized in the field are listed below :—

(1) Enemies of the major pest pears, *O. inermis* and *O. stricta*.

The moth borer, *Cactoblastis cactorum* Berg. from the Argentine.
The moth borer, *Olycella junctolineella* Hulst. from the United States.
The Coreid bug, *Chelinidea tabulata* Burm., from the United States.
The Coreid bug, *Chelinidea vittiger* Uhler, from the United States.
The cochineal, *Dactylopius opuntiae*, Ckll., from the United States.
The Cerambycid beetle, *Moneilema ulkei* Horn, from the United States.
The Cerambycid beetle, *Moneilema variolare* Thoms., from Mexico.
The red spider, *Tetranychus opuntiae*, Banks, from the United States.

(2) Enemies of the lesser pest pears.

The moth borer, *Tucumania tapiacola* Dyar, from the Argentine, attacking *O. aurantiaca.*

The Cerambycid beetle, *Lagochirus funestus* Thoms., from Mexico, attacking *O. streptacantha* and *O. tomentosa.*

The cochineal, *Dactylopius ceylonicus* Green, from Argentine, attacking *O. vulgaris.*

The cochineal, *Dactylopius opuntiae* Ckll., a strain from Mexico, attacking *O. streptacantha.*

The cochineal, *Dactylopius* sp. affin. *confusus* Ckll., from Argentine, attacking *O. aurantiaca.*

The cochineal, *Dactylopius newsteadi* Ckll., from the United States, attacking *O. imbricata.*

Most of the insects introduced for the control of *O. inermis* and *O. stricta* attack some of the lesser pest pears with comparative success.

Success of the Campaign

The original aim of the Board was to establish an insect complex of several or many species, whose combined activities might be expected to exercise some degree of control. In order that the insects might increase rapidly, care was exercised to eliminate their American parasitic and predacious enemies. During the period 1921 to 1924, the insects successfully acclimatized in the field were *Olycella junctolineella, Chelinidea tabulata, C. vittiger, Dactylopius opuntiae* and *Tetranychus opuntiae.*

By the end of 1927, when *Cactoblastis cactorum* began to assume control of the situation, the bug, *C. tabulata,* the cochineal, *D. opuntiae,* and the red spider, *T. opuntiae,* were distributed throughout the prickly-pear territory and had increased to very great numbers. The moth borer, *O. junctolineella,* and the bug, *C. vittiger,* were established at various points and were multiplying successfully. The cochineal and the red spider were causing effective "thinning out" of the densest prickly-pear in the more heavily timbered areas, and *Chelinidea* was proving its value in destroying the fruit and generally devitalizing the plants. There is no doubt that, without the introduction of *Cactoblastis,* the biological campaign would have justified the efforts, although control of the pest would have been much more gradual and probably far less complete.

Since 1927, success has been due to *Cactoblastis,* and the other insects have played a very minor role. Indeed, they have been unable to withstand the competition of the more effective destroyer. With the exception of the cochineal, they have dwindled in numbers and appear to have disappeared completely from large sections of the country. Thus, in Western and South-west Queensland, where *Chelinidea tabulata* occurred in enormous quantity in 1927, not one example has been seen for three or four years. Cochineal has contrived to maintain its existence and to cause, at times, some destruction of fruit, seedlings and young growth.

Cactoblastis cactorum is a native of the Argentine and Uruguay. Other species of the genus attack cactus plants in Brazil, Argentine, and Peru. They belong to a group of Phycitidae containing seventeen recognized related genera and at least fifty species, all of which tunnel as larvae in the stems or fruit of prickly-pear and other cacti. The Phycitids form the most dominant group among the cactus insects ;

FIG. 1.

Typical dense *Opuntia inermis* in forest country, Chinchilla, Queensland, prior to attack by prickly-pear insects.

FIG. 2.

The same area photographed in October, 1939, showing complete destruction of pear by *Cactoblastis cactorum* Berg.

Fig. 3.

Fig. 4.

Fig. 3.—Rhodes grass (*Chloris*) growing on former dense pear area, Chinchilla, Queensland, December, 1931. The timber has been burnt and the area planted with grass for the purpose of grazing dairy cattle.

Fig. 4.—A new settler's home and improvements near Chinchilla, Queensland in May, 1932. The whole scene was dense prickly pear in 1937 and was reclaimed through the agency of *Cactoblastis*.

one or more species occur in practically all sections of North and South America where cactus plants are indigenous. *C. cactorum* was introduced from the Argentine in May 1925. The one shipment comprised approximately 2,750 eggs which reached Australia in the larval stage. The larvae pupated in the spring and the moths deposited 100,650 eggs. These eggs were accommodated in rearing cages and the ensuing generation, in February-March 1926, yielded 2,540,000 eggs. Hence, the increase in twelve months was 900-fold.

The first experimental liberations were made in February-March 1926. Mass rearing in cages was continued until the end of 1927, by which time 9,000,000 eggs had been distributed in lots of from 100,000 to 250,000 at various selected points scattered over the pear territory. Owing to the increase of stocks at the earliest liberation sites, cage rearing then became unnecessary. Mass distribution, in which the State prickly-pear organizations were associated, was commenced in 1928 and was completed in 1930. For the first eighteen months of this period, pupae were collected in large numbers from the field in cages, where the moths emerged and oviposited, the eggs being gathered daily; 400,000,000 eggs were secured in this way for distribution. By the middle of 1929, the numbers in certain field centres were so great that the eggs were obtained direct from the plants; 2,350,000,000 eggs were collected by this method in 1929-30. The total number of eggs utilized for distribution was roughly 3,000,000,000.

It will be observed that the insect was distributed in the egg stage. The eggs are laid in long chains or sticks, containing an average of about seventy-five individuals; the "eggsticks" can be handled and transported without injury, and, as the incubation period occupies three to five weeks, distribution was simplified. The eggsticks were lightly glued on squares of paper or were placed in waxed paper quills; the squares or quills were pinned to the pear plants. In Queensland, with its great tracts of prickly-pear lands, gangs of men were employed for gathering and preparing the eggsticks for distribution, and motor vehicles with other gangs were used to travel all passable roads and tracks running through and into the dense masses of pear. Within six years of its importation, *Cactoblastis* was established from one end of the pear belt to the other. Further distribution has not been found to be necessary, except on a very limited scale for isolated areas or in other particular cases.

Life History and Habits of Cactoblastis

There are two generations annually, a shorter summer and a longer winter generation; in Central Queensland and to a slight degree in the more southern districts of this State, an additional partial generation occurs in the autumn. The main moth emergence periods are September-October and January-February; in the more southern districts of New South Wales, emergence is about a month later in both generations. The winter is spent in the larval stage.

The females may deposit as many as 300 eggs, but the average is 100 to 120 per individual. The larvae are truly gregarious; they burrow into the cladodes as soon as they hatch and remain as internal feeders throughout their life. When about one half grown they frequently vacate the cladodes and wander round the plant for a few

hours before entering at a new point or points ; this habit appears to be associated with the division of the original colony into two or more components. During very hot weather, the larvae often cluster on the underside of the cladodes, returning to their interior quarters after the heat of the day. The gregarious habit terminates at pupation time, when the larvae make their exit from the plant singly to spin the silky cocoons under debris, fallen joints, the bark of trees and logs, or in similar protected situations. The pupal stage occupies three to six weeks. The moths are nocturnal but the larvae are mainly diurnal in habit.

The Manner of Destruction

Prickly-pear has a moisture content averaging about 90 per cent ; hence, the succulent cladodes are susceptible to destruction by internal feeders. *Cactoblastis* larvae devour the whole interior of the cladodes, except for the vascular bundles, leaving the thin parchment-like cuticle undamaged. However, their activities are generally accompanied by rotting brought about by various associated bacteria and fungi. The larvae tunnel freely from joint to joint, even into the underground butts of the plants. In the case of older large plants, they rarely penetrate into the basal portions. The complete disintegration of the older plant appears to be due to the concentrated attack of large numbers of larvae in the upper growth causing a breakdown of the tissues of the lower portions, pathogenic organisms being associated with the decay. A light infestation of larvae is insufficient to bring about destruction. The insect population must be heavy. Hence, although various diseases, bacterial in the younger growth and fungal infections in the thicker lower stems, contribute toward the destruction, their role is dependent on the numbers of the insect.

The rapidity with which prickly-pear collapses from the attack is influenced by the succulence of the plants. Young plants and the succulent growth occurring in brigalow (*Acacia*) and belar (*Casuarina*) scrubs frequently become a rotting mass after one heavy onslaught by the insect. The harder or less succulent plants, growing in more open country, may require several successive attacks to bring about their breakdown. Certain "resistant" types of *O. inermis* and *O. stricta*, notably those with a low nitrogen or high starch content, are not readily destroyed.

Collapse of the prickly-pear does not mean eradication, but is generally followed by the appearance of re-growth from the butts. The amount of re-growth varies, and is often heavy ; it grows vigorously, much more rapidly than the original plants, and may reach dense proportions within three years. All re-growth is of a succulent nature, being a more or less forced growth, and is more susceptible to destruction by *Cactoblastis* than primary pear. There may be two or more waves of re-growth before the infestation is eradicated or reduced to scattered proportions.

Although *Cactoblastis* moths are free-flying and have been known to disperse for at least several miles, they prefer to deposit their eggs in the immediate vicinity of the point of emergence. For this reason, the first destruction occurs at the actual liberation site and then spreads outwardly, and a large area of dense prickly-pear frequently collapses completely during a period of a few weeks.

Collapse of the Dense Pear Areas

The success of *Cactoblastis* was apparent almost from its introduction. From the first experimental liberations made in February-March 1926, the insect had increased very greatly within 15 months at several widely separated localities and had killed out many large plants and clumps ; the numbers originally released of from 80,000 to 250,000 eggs had multiplied to several millions of larvae in these areas. Twelve months later, by June 1928, several liberations revealed the collapse of dense pear cover from several hundred to fifteen hundred acres, vast numbers of insects in the general vicinity, and a natural spread of from 10 to 15 miles.

The mass distribution of eggs in 1928 to 1930 was followed by a greatly accelerated rate of destruction, and in 1930 to 1932 the vast stands of prickly-pear throughout Queensland and in the north-west districts of New South Wales were reduced to decayed pulp in a most spectacular manner. The last big tract of dense original pear in Queensland was destroyed in 1933. The rapidity of the onslaught by *Cactoblastis* was a striking phase of the campaign. For example, in one continuous belt of 100 miles of dense growth, distribution was carried out in 1929 ; in August 1930, the establishment of the insect was very light and there was no evidence of any destruction ; yet, in August 1932, exactly two years later, 90 per cent of the pear had disappeared from this large tract of country.

Re-growth

The destruction of prickly-pear, as already discussed, has dealt with the primary or original pear flourishing prior to the use of insect control methods. The collapse of the primary pear throughout the greater part of Queensland and New South Wales in the space of two to three years meant an enormous drop in the *Cactoblastis* population through starvation, and was followed by a big wave of re-growth in 1931 to 1933. With the exception of Central Queensland, where a second growth has never been an important factor, the re-growth was common to all districts, and in many areas soon reached the density and vigour of the original infestation. The recurrence was viewed with some degree of apprehension, particularly as the *Cactoblastis* population had become so light. However, by 1933 it was obvious that the insect was recovering very quickly ; indeed, its rate of increase was more rapid in this young succulent growth than in the primary pear. At the end of 1934 the large areas of re-growth had been brought under control. Subsequently there have been no big waves of recurring growth. True, it has appeared in many places and has persisted for three or four years in certain areas, but since 1934 it has not given any cause for alarm.

Resistant Prickly-Pear

Mention has already been made of forms of the major pest pears that have proved more difficult to eradicate, owing to the inability of *Cactoblastis* to increase moderately rapidly in such areas.

The more common of these resistant types is generally known as "yellow pear," a rather chlorotic, usually stunted, slow-growing plant, bearing relatively few fruits, which is associated with poor soil conditions. Yellow pear usually occurs on hilly

or ridged timbered country and is deficient in nitrogen. In Queensland, this type was not found freely, being confined to small areas among better class prickly-pear ; hence, it did not constitute a problem. In New South Wales, however, there were two districts, the Bingara-Inverell country in the north and the Hunter Valley, where yellow pear was dominant, and where, in consequence, progress by *Cactoblastis* was slow.

Experiments conducted by the Board revealed that the relative failure of the insect was due to the low nitrogen content. When given a moderate application of a nitrogenous manure, yellow pear was transformed to a green plant well suited to the requirements of *Cactoblastis*. It was then ascertained that the problem was capable of ready solution if the standing timber were destroyed, thus freeing the prickly-pear from competition for available nitrogen. The application of this practice has given excellent results.

The second type of resistant pear varies somewhat in character, but is always a robust thick-jointed plant with an abnormally high carbohydrate content. The separate areas of this form were comparatively limited in extent and in Queensland have now vanished, as a result of repeated attacks by *Cactoblastis*. The terminal young growth provided a suitable food-supply, but few larvae were able to survive in the starchy older cladodes. Each successive onslaught by the larvae resulted in a greater production of young succulent growth, in which a greater number of insects of the next generation was able to develop. After several repetitions, the plants were destroyed. In the Hunter Valley, New South Wales, areas of this class of growth still survive on elevated hills where climatic considerations play a part in checking the increase of the insect.

THE PRESENT POSITION

In Queensland, the original infestation of *O. inermis* and *O. stricta* and the subsequent waves of heavy re-growth have been destroyed. In many districts the pest has been eradicated, except for a few scattered plants. In other sections there are patches of re-growth or plants of seedling origin, some relatively dense, but such areas are comparatively few in number, restricted in size, and scattered at intervals, often wide intervals. It is quite safe to estimate that the former great bulk of the weed in the State has been reduced by 95 per cent.

In New South Wales, the destruction is not so advanced as in the neighbouring State. There is comparatively more re-growth and seedling pear on the better soils of the north-western and western districts, and some original pear still persists in the resistant areas of the Bingara-Inverell and Hunter Valley districts. The quantity of the pest has, however, been reduced by at least 75 per cent.

A feature of the past five years has been the development of seedling pear either on former pear lands or on bordering country where the soil must be heavily infested with the seeds which are viable for 15 to 20 years, possibly longer. The opening up and stocking, especially with sheep, of the pear country has given an impetus to the germination of the seeds.

The wide scale reclamation has transformed the character of the country from

brigalow and belar scrubs and lands more or less heavily timbered with *Eucalyptus* and other trees and shrubs to open grazing pastures. Under the new circumstances, *Cactoblastis* is faced with conditions differing radically from those of 10 years ago. In the first place, the open nature of the pastures and the lack of protection formerly afforded by the trees and shrubs render the insect more directly affected by local seasonal and climatic conditions. Its increase is now largely determined by these factors. The pupae in particular are susceptible to heat, and may suffer considerable mortality during summer heat waves. In a season of mild temperatures, there is little pupal mortality. The effects of high temperatures are greatly minimized if earlier rains have stimulated the growth of grass and herbage, which afford the necessary protection for the pupae. The length of life of the adults and the number of eggs deposited by the females are reduced if heat waves occur during the period when the moths are on the wing ; and, of course, extremes of temperatures are greater in exposed country than in timbered lands.

Secondly, the quantity and continuity, as regards both distance and time, of the food supply have altered the situation. Prior to the eradication of the great bulk of the primary pear and the subsequent waves of heavy re-growth, there was ample food in the vicinity of that recently eaten and destroyed. Hence, the moths emerging from large concentrations of larvae had no difficulty in finding host plants for oviposition. As a consequence, seedling pear springing up on improved pastures or new re-growth appearing from collapsed primary pear immediately received the overflow population from the near-by dense pear, and such new growth was usually destroyed before it could reach the fruiting stage. At the present time a continuous belt of pear does not exist. The plants are scattered, or occur in quantity only at intervals. In order to destroy an area of seedling plants or re-growth, the insect must now multiply on the particular area from a small initial nucleus. The rate of increase, and hence the time required to bring about destruction, depend upon seasonal conditions. Thus, new infestations of prickly-pear are prone to develop to the fruiting stage before there are sufficient insects to cause their destruction.

In view of the present circumstances, the *Cactoblastis* population is being well maintained. Heavy concentrations are found among remaining areas of denser growth. The percentage of the widely scattered, and even the very isolated, plants attacked by the larvae is consistently high, surprisingly so in many places. The insect has not died out in any area, even when it has reduced the food supply to a minimum. It still possesses the capacity to increase from very small to large numbers within a year or two. Although a little redistribution has been carried out in a few areas, it has not been performed by the Board and has not been really necessary.

It might be said that over the greater part of the former infested country, the pest is under complete control, for the scattered remaining plants cannot be considered of importance and do not constitute a menace. In some districts, the amount of surviving pear is still large enough to reach weed proportions, but is a mere fraction of the former infestation. There is no reason why these remaining heavy or comparatively heavy infestations should not be reduced to scattered plants within a few years.

CONTROL OF THE LESSER PEST PEARS

The cochineal, *Dactylopius ceylonicus*, a native of the Argentine, was introduced from Ceylon in 1913. Within a few years it had virtually exterminated areas of *Opuntia vulgaris* in Queensland and New South Wales, and has since been successful in controlling patches of this plant in Victoria and South Australia. *O. vulgaris* has almost completely disappeared in Queensland, although 25 years ago it was not uncommon in several coastal districts between Brisbane and Townsville.

Several years' observations were necessary in order to ascertain that *Cactoblastis* and the other introduced insects would not effectively control *Opuntia aurantiaca*, *O. tomentosa* or *O. streptacantha*. Special attention was not given to the importation of particular enemies of these plants until success in the campaign against the major pest pears could be anticipated.

The low-growing tiger-pear, *O. aurantiaca*, is undoubtedly the most important of these plants, on account of the rapidity of its spread and the difficulty of its eradication by chemical and mechanical methods. Biological investigations were conducted in the Argentine in 1931-35. The cochineal, *Dactylopius* sp. affin. *confusus*, was introduced in 1932 and the moth borer, *Tucumania tapiacola*, in 1935. Both are now established in the field. The cochineal is causing very effective injury, 90 per cent of dense areas of considerable acreage having been destroyed.

Concerning the tree-pears, the form of *Dactylopius opuntiae* attacking *O. inermis* and *O. stricta* destroys the seedlings and thins out the very dense areas of *O. tomentosa*, but is not effective among the light infestations. A special Mexican strain of this insect causes similar damage to *O. streptacantha*. The Cerambycid, *Moneilema ulkei*, attacks both plants ; it has not proved of value against *O. tomentosa*, but, although its increase is slow, it has brought about good destruction in a few patches of *O. streptacantha*. Another Cerambycid, *Lagochirus funestus*, imported from Mexico in 1935, has been reared and released in numbers. Breeding and distribution work is being continued. The insect is firmly established and is increasing at many liberation sites, where the work of destruction is most promising.

THE RECLAMATION OF PEAR LANDS

It is difficult to paint an adequate picture of what the control of prickly-pear has meant, particularly to Queensland, where the twenty odd millions of acres of dense pear, in addition to the greater acreage of more scattered infestation, are now occupied and are under some type of production.

With 30 miles of railway lines on the better class soils, there are hundreds of new settlers (with their homes and farming or grazing improvements) engaged in dairying, general farming, and the raising of fat cattle. Many areas of former dense pear are being used for such crops as cotton and wheat, and to a lesser degree, maize and other products. The dairying industry in many districts has been given a marked stimulus. In the larger, purely grazing areas, the country has been improved by the destruction of the standing timber to make way for grasses, by the erection of fences and by the provision of water storage tanks and dams. Herds of cattle and flocks

of sheep are now grazing in the former tracts of dense pear where grass, and consequently stock, were absent ten to twelve years ago. Queensland's wool-growing and cattle industries have received a great impetus. The new prosperity is reflected in the growth and improvement of the many townships of from 500 to 3,000 inhabitants within the former pear territory; townships once stagnant are now alive from a business standpoint, with new shops, offices, public buildings and many new homes. The worth of *Cactoblastis* to Queensland is only now being revealed. For the new order of things is of very recent origin and the full value of the additional wealth produced by the former pear lands will not be realized fully for several years.

In New South Wales, with its much smaller belts of heavy pear divided among various districts, the progress is not as obvious as in Queensland. Yet most of the State's pear land is now under occupation. The reclamation has meant, for the greater part, more areas under sheep and cattle, and great numbers of stock on existing properties. Both wheat farming and dairying are being conducted on former pear country in some districts. Whatever happens in the future, the great bulk of the pear territory has been reclaimed permanently. It can never revert to its former useless state.

E. Bruce Levy New Zealand

PASTURE WEEDS

1. THEIR ECOLOGICAL RELATIONSHIP TO THE PASTURE SWARD

In any plant population within any one climatic zone, competition is a master factor in deciding the ultimate floristic identity of a community ; as far as pastures are concerned, sward density and pasture utilization predetermine competition intensity. Light and shade are the two factors controlling competition ; light intensity tends to promote stability while shade intensity tends to promote change, that is, the plant which can keep its canopy in the light assumes and maintains dominance, but the moment it becomes shaded by a more vigorous rival it loses dominance and may ultimately be eliminated altogether from the community. Plant succession is fundamentally based upon on this factor of light and shade, the pioneer becoming the foster parent of a plant or an association that ultimately overtops it and seals its doom. This in turn may be overtopped by a still more vigorous grower, one plant community thus following another in progressive succession (Figs. 1 and 2.)

Within the community, micro-climates of relatively weaker light and denser shade are set up, but within these again the same principle applies. In retrogressive succession wherein the tall growing plants are destroyed by the axe, by cattle, or by fire, the reverse procedure takes place. Light becomes more intense on the ground surface and the more it is prolonged and intensified the more is the original pioneer vegetation likely to become dominant again (Fig. 3). Such retrogressive successions are very clearly depicted in New Zealand, where the original forest or tussock grass cover has been destroyed by burning and intensive stock grazing. Actually the establishment of the grass sward on our deforested hill country has been a process of retrogressive succession, particularly where the struggle against shrubby growths following the forest fire and seeding has been keen. It is not only the growing plant which is influenced by light and shade ; seed germination is also governed by light stimuli, and each species appears to be extraordinarily sensitive to the degree of light or shade intensity.

In a pasture sowing, the early established species may have a marked effect on the actual germination of the slow establishing species ; even in a pure sowing of one species, the first seeds to germinate may further retard this process in the slower germinating seed and the latter may remain for years under light intensity inadequate to stimulate germination. Thus, in hill country development in New Zealand, where the first sowing has been overcome and the sward completely eliminated by secondary growth, it is not unusual, on clearing and burning after a period of ten or more years, to find red clover (*Trifolium pratense*), alsike clover (*Trifolium hybridum*) or white clover (*Trifolium repens*) germinating from seed which has lain dormant for the duration of the secondary growth. Similarly, weed seeds

may remain dormant in the ground for 50 or more years, and germinate when the correct light stimulus reaches them ; if areas that have been in grass for 40 or more years are ploughed in the spring or autumn, many annual or perennial weed seeds germinate as soon as they are turned up to the influence of light. Docks (*Rumex obtusifolius* and *R. crispus*), *Coronopus didymus*, *Amarantus retroflexus*, *Chenopodium album*, *Cirsium lanceolatum* and *Brassica campestris* may be cited.

Similarly, in the primary forest burns in New Zealand, wind-borne seeds of *Cirsium lanceolatum*, *Erigeron* spp., *Erechtites* spp., etc., or bird-disseminated seeds such as *Phytolacca octandra*, or *Solanum nigrum* spring to life as soon as the forest shade is removed and they may become the dominant vegetation during the first year of the burn. Seeds of secondary growth trees such as *Fuchsia excorticata*, *Aristotelia serrata*, *Melicytus ramiflorus*, *Nothopanax arboreum*, *Brachyglottis repanda* and spores of bracken fern (*Pteridium aquilinum* var. *esculentum*), water fern (*Histiopteris incisa*) and hard fern (*Paesia scaberula*) may also germinate as soon as the light of day is admitted to the forest floor. Before the felling and burning of the mature primary forest, these species of shrubby growth and the ferns exist only in breaks in the forest. Few of our forest trees themselves can re-establish from seed shed under their own shade. The majority need more open scrub associations where the light intensity is sufficient to stimulate their seed to germinate.

The same is true of many pasture weeds. At this Station* the soil type is such that rush (*Juncus effusus*) may become troublesome. No rushes have seeded on the area during the past ten years ; yet in 1939 when a comparative trial was made with pedigree Italian ryegrass (*Lolium multiflorum*), ordinary certified Italian ryegrass, ordinary uncertified Italian ryegrass and Western Wolths ryegrass (*L. multiflorum* var.), relative persistency and sward density could be measured by counting the number of rush plants established in the series of plots after 12 months. There was considerable increase in bare patches in the plots of Western Wolths ryegrass which crop had thinned out considerably and was overgrown, after 12 months, with a mass of young rushes, while the pedigree Italian ryegrass plot was practically free of rushes, because it had maintained a good winter cover. Similarly, in trials with strains of perennial ryegrass (*L. perenne*), relative persistency may be judged by rush establishment in the first year after sowing ; the certified true perennial persistent strains create a shade intensity too great to permit stimulation of dormant rush seeds, while in becoming more open, the uncertified false perennial strains allow light to penetrate to the soil surface and germination of rushes takes place.

This principle of weed control in pasture establishment cannot be over-emphasized. It applies not only to the strain of seed and the quantity used per acre, but also to methods of stocking, drainage, etc. Any factor that breaks the turf, or weakens it sufficiently to allow the light to penetrate to the ground surface, indirectly brings about the germination of weed seeds lying dormant in the soil. In this connexion winter trampling by cattle, even of well-established pastures, may lead to a crop of *Ranunculus* spp., *Cirsium lanceolatum*, or *Mentha pulegium* in the following spring or summer. Breaking the turf in summer also promotes weed germination and

*Palmerston North.

establishment in the following autumn. The examples of barley grass (*Hordeum murinum*) around trees where stock camp for shade, *Marrubium vulgare* and *Carduus tenuiflorus* on the sheep camps of the dry hill country may be cited. *Poa annua* is often dominant in worn playing greens and about sheepyards, pathways, etc.

In the hay or seed crop, a temporary weakening in the density of the sward occurs as a result of the dense canopy and its subsequent removal, and annual weeds such as *Bromus mollis*, *Anthoxanthum odoratum*, or perennial weeds such as *Plantago lanceolata*, *Taraxacum officinale*, etc. increase after each weakening in the sward density. On the other hand, if these pastures are grazed for some consecutive years and the sward density increased, the annual weeds gradually succumb and are no longer troublesome in the sward while these grazing conditions prevail. In connexion with seed or hay production, speed of recovery of the sward and an early recovery of sward density generally militate against annual weed invasion. It is usually true that the farmer who has maintained a high soil fertility and can apply periodically high stock concentrations to the stubble aftermath may generally harvest seed or hay year after year with comparative impunity as far as weeds are concerned. Generally, however, by taking hay repeatedly from a mixed sward the shade-enduring top grasses eliminate the light-demanding bottom grasses, the former becoming dominant. Thus, cocksfoot (*Dactylis glomerata*), timothy (*Phleum pratense*), Yorkshire fog (*Holcus lanatus*) and *Paspalum dilatatum* may assume dominance over perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) under repeated haying, the factor of light and shade again influencing the situation.

Perhaps the greatest factor in the spread or control of weeds in pastures is the system of grazing practised. Close and continuous grazing by stock is the most fruitful method of inducing pasture weeds (Fig. 4). In this system the light factor at ground level is potentially active ; not only is the germination of weeds seeds made possible, but the spread of creeping and tillering weeds is also greatly facilitated. In the latter case, light reaches the creeping stolons and these remain close to the ground surface ; as a result of this, root formation takes place at the nodes or along the creeping stems and a healthy mass of creeping weed growth may dominate the pasture. *Bellis perennis*, *Mentha pulegium*, *Ranunculus repens*, *Cerastium vulgatum*, *Prunella vulgaris*, *Modiola multifida*, piri piri (*Acaena sanguisorbae*) and *Paesia scaberula* may be cited as examples. In playing greens, the fact that weeds spread due to admission of light to the ground surface through close and continuous mowing is well known, and much of the art of greenkeeping consists in combating this flat- and mat-weed flora by the use of " toxic " fertilizers and poisonous sprays.

Shallow underground rhizomes or short tillering underground rootstocks are also sensitive to surface light and shade. These organs are encouraged by close and continuous grazing, while intermittent grazing, which permits a greater shade density at the ground surface, retards their extension. The rush plant is a typical example among the weeds (Figs. 5 and 6) and *Danthonia pilosa* among the grasses. The success of *Danthonia pilosa* as a pasture grass under close and continuous grazing is primarily attributable to its demand for light to the crown, which ensures the healthy condition of its short underground tillering rootstock.

Control of creeping and underground tillering weeds is closely connected with creating shade at the ground surface. Such shade retards further extension. In many cases of positive heliotropism, the creeping stolons rise off the ground towards the light, thereby preventing rooting and also making the plant much more vulnerable to grazing stock. This principle of shade creation through spelling the pasture (resting by removal of grazing animals) is widely used in pasture management and much of the value of rotational grazing may be attributable to the comparatively long period of shade to the ground in relation to the short period of grazing.

Annual weeds owe their persistency very largely to the fact that critical periods for pasture growth generally occur in the summer months, when there is much bare ground affording a high light intensity to the surface. Immediately rain falls, the conditions are propitious for the successful germination and establishment of the annual species. Annual meadow grass (*Poa annua*), hair grass (*Vulpia bromoides*), *Bromus mollis*, *Bromus sterilis*, *Hordeum murinum* and *Carduus tenuiflorus* may be cited as examples. The principle also holds for the successful establishment of annual clovers in the pasture. Unless bare patches occur in the pastures regularly in autumn, these clovers fail to become re-established. Some of the annual clovers, such as spotted burr clover (*Medicago maculata*) and toothed burr clover (*M. denticulata*), are weeds of pastures. Even on moderately good soil they are re-established by smothering out the associated perennial species during the preceding spring and summer growth ; at the end of their growing season, their death leaves bare ground and suitable conditions for seedling establishment. Subterranean clover (*Trifolium subterraneum*) and suckling clover (*T. dubium*) are useful annual clovers which become established in this way.

Soil moisture and temperature govern to a marked degree the weed flora which may develop, but the mode of their introduction is still determined by the light and shade intensity of the environment. Water-logging and water-lodging on the surface in the winter break or weaken the turf, allowing full light to reach the soil surface. Weed establishment is certain to occur in the following spring, before the bare patches become overgrown. *Rumex* spp., *Mentha pulegium*, *Juncus* sp., *Polygonum hydropiper*, *Ranunculus* spp., *Plantago major* and tall fescue (*Festuca arundinacea*) are frequently introduced in this manner. The importance of drainage to prevent water-logging or water-lodging on the turf for any length of time is obviously a control method which is too often neglected. The point at issue, however, is that the break in the turf is the important ecological factor in weed establishment under wet soil conditions.

Summer temperatures may similarly cause breaks in the sward. If the temperature is tropical or subtropical, the weed flora will be of a tropical or subtropical character, but, as in the case of water-lodging, the factors of light and shade are largely responsible for the germination, establishment and spread of weeds, that is, while the turf remains dense and the ground surface shaded, few pasture weeds can become successfully established from seed therein.

It is known that it is impossible to secure a dense compact turf under all grassland conditions at all times of the year. The winter period of shortage and the lean

summer period often tend to favour the practice of overgrazing a pasture to an extent which permits the penetration of light sufficiently strong to germinate seed and spread established plants. If more attention were paid to sward density and rotational grazing to provide periodic shade with the minimum periods of close grazing, weeds would not be so prevalent in permanent pastures (Fig. 7).

Topdressing with artificial manures to stimulate quick recovery of the sward after grazing and to increase growth and density of the pasture is a vital factor in weed control. Mat-weeds and flat-weeds of pastures may be almost entirely eliminated by stimulation of the high-producing grasses and clovers. In the control of secondary growth, topdressing aids in thickening the turf and thereby ensures that a greater number of cattle and other stock may be carried per acre.

Density in New Zealand pastures is best secured by the use of any of the following sets of pasture species :—

(1) Ryegrass—white clover.
(2) *Paspalum dilatatum*—ryegrass—white clover.
(3) Cocksfoot—ryegrass—white clover.
(4) Browntop—crested dogstail (*Cynosurus cristatus*)—*Lotus major*—white clover.
(5) *Danthonia pilosa—Poa pratensis*—New Zealand ricegrass (*Microlaena stipoides*).

Soil fertility and climate are factors which will determine choice of any one set of the above species. For the first class high-fertility soils, the ryegrass—white clover association has proved itself the best under New Zealand conditions. This association conforms to the best principles in pasture exploitation—high production per acre ; high palatability ; dense sward formed even under fairly close grazing and an ideal sward under rotational grazing.

Paspalum is essentially a top grass, but makes a dense turf under hard grazing ; nevertheless, its yield under close grazing is small compared with its potential yield when permitted to make tall top growth. The use of *Paspalum* in the north of the North Island, however, has been the means of clearing thousands of acres of weed infested land—*Festuca arundinacea*, *Juncus* spp., *Mentha pulegium*, *Plantago major*, *Rubus fruticosus*, *Paesia scaberula*, *Acaena sanguisorbae*, bracken fern, *Leptospermum scoparium*, etc. If *Paspalum* were used more in the north, in association with perennial ryegrass and white clover, almost weed-free pastures would be assured.

Cocksfoot-dominant pastures control weeds, but only if lightly grazed. Unlike *Paspalum* or perennial ryegrass and white clover, cocksfoot does not form a dense sward under close grazing ; therefore, under these conditions the cocksfoot sward is of little value for weed control. This point is emphasized in connexion with the production of cocksfoot seed ; if the cocksfoot remains ungrazed, pure stands continue and seed crops free of weeds and other impurities may be reaped, but once the stand is opened up by grazing, even for comparatively short periods in the winter, impurities such as ryegrass, Yorkshire fog, ribgrass, etc., are introduced ; if the grazing is continued, seed production becomes impossible. Cocksfoot rapidly declines under hard grazing and becomes open to invasion by all classes of weeds.

On the second class, low fertility, wet soils, the browntop (*Agrostis tenuis*) dominant sward, associated with *Lotus major*, crested dogstail and some white clover in the higher rainfall belts (60-100 inches), makes a dense turf that will tolerate moderately severe grazing. The yield of such a pasture is not very high (up to 1.5 to 3 ewes per acre), but the sward density is such that weed control is secured cheaply. Many thousands of acres in the North and South Islands have been prevented from becoming weed infested by the introduction of browntop and its associated species. Countless efforts to grass the wet Taranaki country (60-100 inches rainfall) permanently in the face of manuka (*Leptospermum scoparium*), hard fern, bracken fern, piri piri, etc., with the non-sward-formers or high-fertility demanding species, such as perennial ryegrass, cocksfoot, white clover and red clover, failed. It was not until the introduction of mixtures of browntop, *Lotus major*, crested dogstail and white clover that successful control of secondary growth was effected.

Danthonia pilosa with its associated species acts similarly to *Agrostis tenuis* where the rainfall is low (25-35 inches) ; its great value lies in the fact that it carries a fire well, and does best under close grazing. *Danthonia pilosa* will not resist shade for long ; it can be readily smothered or greatly weakened and opened up by periodic vigorous growth of annual clovers such as *Trifolium dubium*, clustered clover or *T. subterraneum*. On the dry hill country, spelling for a whole growing season is practised to encourage the shade-enduring grasses such as cocksfoot and *Poa pratensis*, and to retard the spread of *Danthonia*. However, from the point of view of weed control, this practice is not necessary, owing to the excellent sward-forming attributes of *Danthonia* under close and continuous grazing.

Kikuyu (*Pennisetum clandestinum*) and buffalo grass (*Stenotaphrum secundatum*) in North Auckland also behave as good sward-formers and are useful for weed control on loose sandy soils, slips, road and railway cuttings, etc. On the wet, waterlogged flood areas, reed sweet grass (*Glyceria aquatica*) and floating sweet grass (*G. fluitans*) behave in a similar manner in the control of rush, tall fescue, etc.

The use of a sward association attuned to soil fertility, soil moisture, climate and grazing management is fundamentally one of the main features in any policy of weed control on pastures. In this, not only are the species important, but also strains within the species will often decide the balance of growth type—on the one side to a dense turf, on the other to an open weedy pasture.

Persistency is a prerequisite for sward density and its deficiency in the major dominants must lead to weed encroachment. With the ryegrass—cocksfoot—white clover group, strain differentiation is extremely marked and the utmost care in buying seed of these three species is necessary. The certification scheme in New Zealand makes possible the purchase of good persistent strains, and evidence from the use of certified as against uncertified seeds points clearly to the value of certification as a measure in weed control.

2. WEED CONTROL IN RELATION TO MANAGEMENT OF THE GRAZING ANIMAL

The grazing animal itself may eradicate or introduce pasture weeds according

to its type and use. In the preceding pages, emphasis has been placed on the light and shade factor. Obviously this factor operates according to the manner of defoliation of the sward, close and continuous grazing introducing the light, intermittent grazing creating conditions of shade. The policy of spelling (resting) for as long a period as possible between grazings commensurate with good utilization by the class of stock employed—a principle enunciated by Hudson (**1**)—is a practical mode of attack and is actually rotational grazing, although the daily shifts and small paddocks usually associated with rotational grazing need not be used. In the control of *Acaena sanguisorbae*, for example, spelling of the pasture to create ground shade so that the stolon is drawn off the ground, thus preventing rooting, together with subsequent stocking with cattle that break the runners by treading and grazing, constitutes a regular practice on steep hill country, which has been very successful in the control of this weed on a large scale. The spelling of country to shade the marginal ring of hard fern, with subsequent stocking by cattle, soon retards the spread of this weed. Hard and close grazing with sheep favours both the above weeds and permits their rapid spread (Fig. 8). *Paesia scaberula* is unpalatable to all classes of stock and the only methods for ultimate control must be along ecological lines, in which the formation of a persistent dense turf with periodic shading and mechanical crushing are the main features.

Leptospermum scoparium, *Cassinia leptophylla*, *Pomaderris phylicaefolia*, *Pimelea prostrata*, and *Olearia Solandri* are weeds of secondary growth which require ecological consideration. They are unpalatable to stock, but are all extremely sensitive to shade and cannot become established from seed in a dense turf. All must have the full light of day, a fact of great ecological importance in their control. The school which advocates cutting these growths and allowing them to lie and gradually rot has based its views on experience of this practice as compared with burning. Burning is effective in control only where there is a sufficiently dense mass of growth to maintain a fire hot enough to consume all foliage and seed capsules and to roast any seeds shed on to the ground surface. A skimming fire merely lets in the light to dormant seed and germination and establishment are certain to follow. For the same reason the burning of standing *Leptospermum scoparium*, *Pomaderris phylicaefolia*, *Cassinia leptophylla*, *Olearia Solandri*, etc., is rarely effective in control, the seed on the plant or on the ground seldom being totally consumed. The light fire merely acts as a ripening process to the seed capsules, which soon open ; the seeds fall to the ground after the burn and readily germinate owing to lack of any ground competition or shade (Fig. 9).

This woody class of weed may be tackled by a sweeping fire or by a series of fires prior to the seeding stage, once a grass sward is established. The practice then is to rest the country for a full growing season and fire this growth in the autumn The grass sward recovers rapidly after the fire ; by a series of burns before the shrubby plants reach a seed-bearing stage, the seed supply in the soil is gradually exhausted and the turf becomes compact as a result of the removal of the shade of the shrubby growths. This ecological principle in shrubby weed control is widely applied in hill country development in New Zealand. The light must reach the crown of the hardier

grasses—browntop (*Agrostis tenuis*), Chewings fescue (*Festuca rubra* var. *fallax*), *Danthonia*, etc., before they can develop into a dense turf. The periodical removal of the shrubby growth by fire is the most economical method of securing this.

Cattle are essential in the control of bracken fern, many thousands of acres having been cleared merely by crushing with cattle (Fig. 10). Ecologically, however, crushing alone as a mode of control leaves much to be desired. The animal must be forced in order to crush successfully and the losses by accident and compaction are high. The use of burning to remove the rankest growth and the sowing of suitable seeds mixtures to make a sward, are fundamentally sound practices. Cattle or wethers must, however, be available in the spring following the burning and seeding, which should have been carried out in the previous autumn. The process of bracken control consists of starving the underground rhizome. As the rhizome is too deep in the ground to become affected by burning or surface treading, the bracken is crushed in the curled stage, a process which is facilitated by the fact that the fern is quite palatable at this stage. Once the fern uncurls, however, control by crushing is more difficult, and the principle of rhizome starvation fails as a means of control. In New Zealand, no economic method of bracken control on country which cannot be ploughed has been effective apart from the use of cattle and the gradual establishment of a dense pasture sward. The more cattle hill country can carry in virtue of a good grass cover, the easier is the control effected, and conversely, the more cattle that must be withdrawn from the hills due to the lack of supporting pasture feed (or to any economic stress that causes cattle to be kept at a heavy financial loss) the more rapid is the deterioration and spread of bracken fern. In other words, cattle are hill implements, and, as far as bracken fern control is concerned, are the only implements that can be applied economically. With other growths the principle is also true, but where the growth is unpalatable, the fire, slashhook, or grubber must be applied along with the cattle ; above all, seeds mixtures composed of appropriate species must be sown because control in the end must be based upon the development of a complete turf cover which can be managed on an ecologically sound basis, having weed control as one of the major considerations.

In the control of persistent shrubby weeds such as gorse (*Ulex europaeus*), blackberry, etc., much labour and money have been wasted through failure to appreciate the value of the grass sward and the grazing animal, after grubbing or cutting the above growths. No major work of control can be permanently effective unless the country is at the same time efficiently grassed and farmed.

The differentially selective grazing shown by various classes of stock may be used effectively in the control of certain weeds. For example, *Senecio jacobaea* under dairying conditions may become a very serious pest, as the plant is not readily eaten by dairy cows ; under regular sheep grazing, however, the weed never becomes a menace. Similarly, sheep readily eradicate *Chrysanthemum leucanthemum* from a pasture, but dairy cows will neglect it entirely and dairying pastures may become covered with the white blossom of this weed at flowering time. Sheep, again, neglect *Acaena sanguisorbae*, while cattle, and particularly horses, will eat the plant fairly readily. *Rumex* spp. and *Ranunculus* spp. may become serious pests under dairy-farming, but are seldom troublesome under sheep.

Goats are useful in the control of shrubby growth such as *Ulex europaeus*, *Coriaria ruscifolia* and blackberry. While goats do not kill the blackberry, they prune it back to the crown and prevent the development and layering of canes, thus rendering the country safe for sheep.

In New Zealand, direct chemical methods to control weeds are applied only in the case of ragwort on dairying country ; sodium chlorate spray or sodium chlorate + lime dry mixture are used. Arsenic pentoxide has been used experimentally on hard fern and is now fairly generally used for weed control in lawns. Here sulphate of ammonia, and sulphate of ammonia + sulphate of iron are also effective in weed control in lawns, but both these methods are unsuitable for grazed pastures. Sulphate of ammonia or ammoniated superphosphate have a specific weed control value when used as a pasture topdressing, in the stimulation of the grasses of the sward. The use of sulphate of ammonia in grasslands, however, should not be carried sufficiently far to kill weeds by direct contact, owing to the damage also suffered by the legumes of the sward.

Practical control on the farm must largely rest, therefore, on the formation of dense pasture swards by strict adherence to persistent strains of the suitable species, on the stimulation of these species by topdressing to a high productive and hence a high competitive level, on the management of grazing in such a way as to afford the sward periods of recovery between grazings in order to keep the ground surface shaded, and finally, on the use of specific classes of stock which graze the weed rather than neglect it. Prevention, however, must always be the keynote of control, and this paper will have served a useful purpose if it has but emphasized the ecological aspect of the problem, both from a plant and from an animal point of view.

Reference

1. New Zealand, Department of Scientific and Industrial Research. Bull. No. 31. Investigations into pasture production. Effect of fertilizers etc. on the yield and chemical composition of herbage. By A. W. Hudson, B. W. Doak and G. K. McPherson. Wellington, 1933. pp. 197.

Fig. 1.

Fig. 2.

Fig. 1.—Young pre-forest phase of *Melicytus ramiflorus, Nothopanax arboreum, Brachyglottis repanda,* etc., established under the canopy of a thicket of *Leptospermum scoparium* (manuka). The shade is too dense for re-establishment of manuka, but favourable to the pre-forest trees. These latter overtop the manuka and smother it.

Fig. 2.—Comparison of plant regeneration due to varying light intensity. On left, within a manuka thicket, the pre-forest phase is becoming established as in Fig. 1. On the right in the open, manuka itself is regenerating from shed seed.

Fig. 3.

Fig. 4.

Fig. 3.—Retrogressive succession from tussock to scabweed as a result of burning and overstocking with sheep and rabbits.

Fig. 4.—Close continuous grazing on quite strong country induces weeds. *Bellis perennis*, catsear, *Plantago lanceolata* and *Chrysanthemum leucanthemum* dominant.

FIG. 5.

FIG. 6.

FIG. 7.

FIG. 5.—Close-up view of base of rush, showing outward spread of undergrowth rhizome under the influence of strong light to ground surface due to weak open pasture turf.

FIG. 6.—Growth form of rhizome of rush. Light at the growing point encourages spread, shade at this point retards further spread.

FIG. 7.—A dense pasture, rotationally grazed, is ideal for the purpose of weed control. A close-up view of a perennial ryegrass-white clover sward.

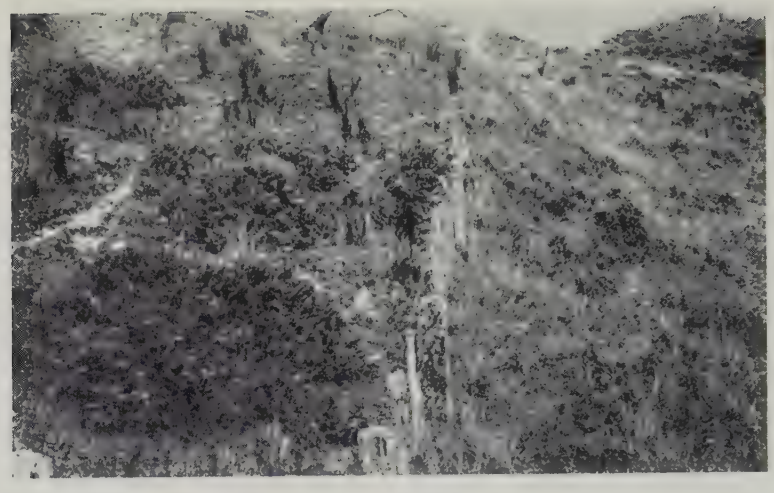

FIG. 8.

FIG. 9.

FIG. 10.

FIG. 8.—Response to differential grazing. Left : close and continuous grazing by sheep; *Paesia scaberula, Acaena sanguisorbae* and *Juncus effusus* dominant. Right: lax cattle grazing, cocksfoot dominant and none of the weeds of the adjoining paddock present.

FIG. 9.—Regeneration of manuka (*Leptospermum scoparium*) from shed seed after a burn through standing manuka.

FIG. 10.—Bracken fern (*Pteridium aquilinum* var. *esculentum*) and *Coriaria ruscifolia* crushed out by cattle.

D. Miller New Zealand

BIOLOGICAL CONTROL OF NOXIOUS WEEDS OF NEW ZEALAND

One of the outstanding agricultural problems in New Zealand is the control of secondary growth, in which the invasion of noxious weeds plays an important part. It has been estimated that of the 11,000,000 acres of original forest land that has been sown in pasture, about 4,000,000 acres have reverted to secondary growth in the first stage towards a re-establishment of the natural plant covering.

Though it is by no means easy to assess the losses due to this state of affairs, the total must reach a very high figure, as a glance at the losses due to a few of the major types of secondary growth will show. For example, there are at least 1,000,000 acres of land, having a potential annual return of £1,300,000, at present occupied by bracken. Again, in the case of the different species of *Acaena*, commonly called piri-piri, the market value of wool is annually reduced by about £250,000 owing to the burrs of these plants. Ragwort, too, must be responsible for very heavy losses, as shown by the information supplied by Dr. Annett, who states that ragwort will reduce butterfat production by at least 30 per cent in a very short time ; he cites the extreme case of a Waikato farmer who had buried his hundredth cow, and who took less than 2,000 lb. of butter fat that year, as compared with 20,000 lb. three years before. Ragwort is also a menace to the honey producer, since ragwort flavour is responsible for the rejection of many tons of honey each year. As for blackberry, the loss due to reduced carrying capacity of the extensive areas of land occupied by this plant must be enormous.

The solution of the weed problem is essentially a cultural one, depending largely upon sound pasture management ; but owing to existing conditions, among which lack of population is prominent, cultural control cannot be altogether depended upon, and additional means have to be sought as auxiliaries. Towards this end, therefore, attention has been given to the possibility of utilizing biological factors, such as phytophagous insects. Although the biological control of noxious insects has now become a well-established system of entomological practice, the application of the same principles in the control of noxious weeds is of comparatively recent origin. It was first attempted about 1902 in the Hawaiian Islands, and somewhat later in Fiji and Australia, but it was not until 1927 that it received attention in New Zealand. The practicability of the scheme has been doubted in some quarters, not so much in regard to its possible effectiveness in the control of weeds, as from the point of view of guarantee which should be given that the insects used as controlling factors will confine their attacks to the weeds in question and not extend their range to plants of economic value.

It must be admitted that this presents a weakness in the application of the

scheme, but a consideration of the situation tends to show that the possibility of specialized weed-controlling insects becoming a menace to economic crops is comparatively remote, although it certainly exists. In the first place, it is well known that certain phytophagous insects may be so specialized as to confine their attention not merely to one genus of plants, but even to one species, and such specialized insects are selected for the biological control of weeds. Further, the fact that most economic crops and weeds in New Zealand are the same as those in the temperate regions of the Old World, and that there the specialized weed-infesting insects —from which selections are made—have remained restricted to their weed hosts, are strongly in favour of the utilization of such specialized insect species; but as there is a possibility of the latter extending their host-range under a new environment, a very careful series of tests under strict quarantine is necessary before liberation can take place. However, in spite of these considerations, one must admit a certain element of danger, as we are far from conversant with, and cannot humanly control, all the factors that govern an insect's habits, while there are on record a few cases of phytophagous insects suddenly extending their host range for some unknown reason.

Nevertheless, if we are to condemn the utilization of specialized phytophagous insects as a factor in weed control, on account of this comparatively rare element of danger, and after all human precautions have been taken, then we must be prepared to have our crops over-run by some, or all, of the many species of phytophagous insects as yet harmless.

Some of the fundamental principles underlying the biological control of weeds are as follows :—

(a) The botanical relationships between the weeds in question and economic plants, since the more isolated a weed is botanically, the less chance there should be of the monophagous members of its insect fauna being a menace to other plants, for example, *Opuntia* spp.in Australia (see article by A. P. Dodd in this Bulletin), and *Senecio jacobaea* in New Zealand.

(b) When the host is closely related to economic plants, as in the case of both *Rubus fruticosus* and *Ulex europaeus*, monophagous insects peculiar only to the weed in question must be selected.

(c) Every insect imported for weed control must be carefully tested under strict quarantine on all economic plants likely to be attacked.

(d) Although at the time of its liberation, an insect may not be of danger to any economic plant already in the country, it should not be forgotten that the occasion may arise when it is deemed favourable in the country's interests to establish another type of economic plant that might be attacked by the insect in question.

Having found, in so far as is humanly possible, that a selected insect is suitable for liberation, additional factors have to be considered :—

(e) That the habits of the host and those of the insect should synchronize, for example, the flowering period must be correlated with the egg-laying period of seed-infesting insects.

(f) The possibility that the weed-controlling insect may be influenced by indigenous parasites, or by those parasites imported and established against some related noxious insect.

(g) The effective control of a weed must be followed up by establishment of pasture or other useful plant covering, as otherwise useless plants, perhaps more difficult to control, may take possession.

When the biological control of noxious weeds was inaugurated in New Zealand, it was decided to deal with what were considered the four major weeds—blackberry, ragwort, piri-piri, and gorse, although the control of the last was to be confined only to the seeds, since gorse itself is of considerable value in parts of the country. The following is a résumé of the attempt to introduce and establish insects against these four weeds.

Blackberry (Rubus fruticosus, &c.)

In regard to this weed, a very serious difficulty lay in its close relationship with important economic plants, and in the omnivorous habits—at least in so far as the Rosaceae were concerned—of practically all the insects known to attack it. Among the insects experimented with, however, there was one that gave promise of fulfilling our requirements. This was a species of Buprestid beetle (*Corocbus rubi*), ranging throughout Southern Europe, the larvae of which tunnelled extensively in the stems of blackberry and certain roses. However, although we found that the larvae of this beetle caused very serious injury to blackberry and certain roses, but to no other plants, not only was the damaged blackberry able to withstand the attack, but the beetles developing from the larvae showed a weakness for the foliage of apple and related fruit trees. As a likely defoliator of fruit-trees the use of this insect had to be abandoned, and with it the biological control of blackberry, since no other insect was considered safe for the purpose.

Ragwort (Senecio jacobaea)

Unlike blackberry, ragwort does not present the difficulty of being related to economic crops, and the selection of likely insects was an easier matter. Of the latter there were several species to choose from, and experiments were made in the first instance with the cinnabar moth (*Tyria jacobaea*) ; the larvae of this insect are confined to ragwort, groundsel, and *Cineraria*. From the outset and during the research, the larvae of the cinnabar moth proved to have a powerful destructive influence upon ragwort, not only devouring the foliage, but also the flowers. After careful tests had been made upon a wide range of plants, the insect was liberated in different parts of New Zealand, and wherever it became established its influence upon ragwort during the period of larval activity was very marked. This insect, however, has not given the desired results. An important difficulty was that only one brood of caterpillars was produced each year, and these were active for only a short period during the spring. Also, for some unknown cause, the insect gradually disappeared even in those localities where it had been able to hold its own for the first few years, although in one location—the ragwort plots in the Cawthron Institu-

tion grounds—it was only last season that any reduction took place. It is noteworthy that the larval parasites of the nearly related magpie moth (*Nyctemera annulata*) attacked the larvae of *Tyria*, but that the pupal parasite (*Echthromorpha intricatoria*) was able to parasitize only the young pupae of the latter moth. Further, the brilliant colours of the *Tyria* larvae—supposed to be a warning to would-be enemies—did not deter birds from engorging themselves until they were unable to take wing.

Owing to the difficulties experienced in regard to *Tyria*, a second species of ragwort-infesting insect was selected and imported for study. This is the ragwort seed-fly (*Pegohylemyia jacobaea*), the larvae of which live in the developing florets and devour the seeds. Work with this insect is still in progress and the results show that, in every floret infested, 100 per cent of the seeds are destroyed. By 1938 we had the seed-fly well established under field conditions on a large experimental area, the insect having successfully passed the winter and infested the spring and summer flowers of the weed.

Piri-piri (Acaena spp.)

The genus *Acaena* being geographically restricted, a search was made for suitable controlling insects in South America, which was considered the most likely place. Although the problem was studied in other parts of that continent, work was finally concentrated in Southern Chile, where two species of insects, both leaf-feeders, a species of saw-fly (*Antholcus varinervis*), and a flea-beetle (*Haltica virescens*), were found to be abundant and to be causing considerable havoc to the weed. These were both brought to New Zealand, but experiments with the flea-beetle were discontinued as it was found to be omnivorous in its diet. The saw-fly, however, had so far proved to be eminently promising, adapting itself readily to the New Zealand environment and to species of *Acaena*. The larvae of this insect feed upon the leaves and also partially upon the burrs, which they finally destroy, however, by nipping through the flower-stalk before the burrs harden.

The habits of the *Acaena* saw-fly reduce to a minimum the danger of attack on other Rosaceae, since the adult insects emerge and lay their eggs in *Acaena* foliage during July, at a time when no Rosaceae of importance, other than the strawberry, are in leaf. It has been found, too, that the insect is unable to oviposit in the leaf of the strawberry owing to the protective vestiture of the latter.

The establishment of *Antholcus* is now proceeding, and the insect has maintained itself and increased in the field during the first two seasons.

Gorse (Ulex europaeus)

This weed presented the fundamental difficulty of belonging to a group of plants of very great economic importance to the Dominion, necessitating care in the selection and use of insects. As gorse is a valuable plant in some parts of the country, the work was designed only for the control of its seeds. For this purpose, the seed-weevil (*Apion ulicis*) was selected, this being a very highly specialized insect confining its attention to gorse-seed and to a less extent to that of broom. As a special safeguard, before it was decided to liberate this weevil,

the tests made upon important Leguminosae under New Zealand conditions were also carried out in England, from whence this insect was secured. The establishment of *Apion* is now proceeding on a wide scale in New Zealand; in the gorse plantations at the Cawthron Institute over 90 per cent of the spring and summer seeds are destroyed, while a survey during the present season of the original area of field liberation showed an infestation of 98.67 per cent. An important difficulty experienced is that a considerable amount of gorse flowers in the colder months of the year, as well as in the late summer, when the weevil does not oviposit. In the late summer flowering, however, there are indications that comparatively little seed develops.

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D. G. Steyn South Africa

THE MOST IMPORTANT POISONOUS PLANTS OF SOUTH AFRICA

In South Africa, plant poisoning in stock is a serious problem. In some years, the losses run into hundreds of thousands of small stock and thousands of large stock. The prevalence of poisonous plants in South Africa, periodic droughts, veld burning, and overstocking are factors mainly responsible for the losses from plant poisoning. More than two hundred poisonous plants are known in the Union of South Africa, and the number will undoubtedly increase with further investigations. Only some of the most important South African poisonous plants will be discussed here.

A. COMPOSITAE

(1) Species of Senecio

The following species of *Senecio* probably constitute our most serious poisonous plant problem :

S. Burchellii DC.
S. ilicifolius L.
S. isatideus DC.
S. glaberimus DC.
S. retrorsus DC.
S. scleratus Schweikerdt, sp. nov.

These plants, commonly known as ragwort, Dan's cabbage, " Kraakstewel ", " Swaweltjiebos ", contain alkaloids, which damage blood vessels and also cause fatty degeneration of the liver and a parenchymatous hepatitis. If the animals survive for any length of time, cirrhosis of the liver follows. Watt, Blackie, some Russian workers and others have isolated various poisonous alkaloids like retrorsine, isatidine, and jacobine from different species of *Senecio*.

Chronic *Senecio* poisoning in the horse is known as " dunsiekte " (" thin-sickness," i.e. loss in condition). A prominent symptom is steady loss in condition. Other symptoms are apathy, pronounced distension of the stomach, loss of sensation, walking about aimlessly with the head held lower than normal, and walking into stationary objects, resulting in serious and extensive wounds, especially on the head. Death is not infrequently caused accidentally by the animals falling into dams (drowning) or from precipices. In chronic cases of *Senecio* poisoning, general icterus is very rarely seen. Interesting features of chronic cases are that animals may develop symptoms only months after they have ingested the plant, and that once symptoms have appeared mortality is almost 100 per cent. If cirrhosis of the liver has set in, it is impossible to arrest its progress. The animals may, and usually do, suffer for weeks or months before they die.

In acute and sub-acute cases of *Senecio* poisoning, jaundice is almost invariably present as a result of the acute parenchymatous hepatitis. In these cases horses frequently exhibit attacks of severe " staggers ". Also the heart action and respiration are severely affected.

Senecio poisoning in cattle is commonly known as " molteno cattle disease " or " straining disease ". Continuous straining often results in prolapse of the rectum.

Senecio ilicifolius has been the cause of many cases of so-called " bread poisoning " in human beings. In certain areas of the Southern Cape Province, this plant is a very prevalent weed on wheat lands. The poorer classes are mainly affected, as they are not very particular in keeping their lands free from weeds. The result is that *Senecio* plants are reaped and threshed with the wheat. Stomach cramps, nausea, vomiting, enlarged liver (hepatitis), which in the course of time becomes cirrhotic and results in ascites, are the most prominent symptoms. Affected individuals may die from within a few weeks to years after symptoms have developed.

Treatment of cases of *Senecio* poisoning is practically of no avail.

(2) Geigeria (Vomiting-bush, "vermeerbos")

Four species of *Geigeria* are known to cause " vermeersiekte " (vomiting disease), but there are undoubtedly more species, especially in South West Africa, which are capable of causing this disease. Those which have been proved poisonous are :—

G. aspera Harv.
G. passerinoides (L'Herit.) Harv.
G. pectidea (DC.) Harv.
G. zeyheri Harv.

At Onderstepoort, Rimington isolated from *Geigeria aspera* a bitter principle, vermeeric acid, which is probably responsible for the symptoms induced by the plant. In years when droughts prevail or when rain falls in winter, these plants may take toll of hundreds of thousands of small stock, as they are very widely distributed. Sheep and goats are mostly affected, but in the worst years cattle, horses and donkeys may also suffer. We recognize four forms of the disease, namely (a) vomiting form, (b) tympanitic form, (c) stiff form, and (d) paralytic form. An animal may, and frequently does, suffer from more than one form at the same time. Vomiting is more prevalent in *Geigeria passerinoides* poisoning than in poisoning with *G. aspera*. The animals may choke fatally while vomiting, or they may die weeks or months later from pneumonia caused by drawing the vomit into the lungs. The disease can be successfully controlled by practising rotational grazing on *Geigeria*-infested and uninfested areas.

(3) Chrysocoma tenuifolia Berg

The plant is commonly known as " bitterbossie " (bitterbush), " beesbossie ', " brandbossie " or " bitterkarroo ", and is the cause of the so-called " kaalsiekte " or alopecia in kids and lambs. As a rule, the mother animals do not suffer, but excrete sufficient quantities of the poison contained in the plant in their milk to poison their young. Symptoms (loss of hair, diarrhoea, sunburn, pneumonia) set in from about three days to three weeks after birth. Weeks and even months after the animals have recovered from the disease, they may die from obstruction of the intestinal canal caused by hair-balls. During the period of loss of hair the animals chew and swallow large quantities of hair. The disease can be prevented by preventing the pregnant animals from grazing for periods of two weeks before to two weeks after lambing on pastures where *Chrysocoma* is prevalent.

B. DICHAPETALACEAE

Dichapetalum cymosum (Hook.) Engl. = Chailettia cymosa (Hook.)

The plant (" gifblaar "; " blaargif "; " poison leaf ") is very prevalent in southern and western Transvaal. Its roots penetrate the soil to a depth of sixty feet and more, with the result that it sprouts before the summer rains fall and when the pastures are still dry. Consequently, the green leaves constitute a great temptation to stock. The active principle, which is a heart poison, is unknown in spite of many years of research which have been spent in attempting to isolate it. The active ingredient is known to be very water soluble, and it is therefore not surprising that animals which have eaten the plant die soon after drinking water. Death is very sudden.

C. LILIACEAE

Urginea burkei Baker

Being a bulbous plant, this species (" Transvaal slangkop ", snake head) sprouts in the early summer months, and in the absence of green and succulent vegetation animals often fall a victim to it. The plant contains two digitalin-like glucosides and the symptoms and post mortem appearances are very similar to those seen in cases of *Digitalis* poisoning (heart-failure and diarrhoea).

D. IRIDACEAE

The following tulips (" tulpe ") have been proved to be poisonous :—

Homeria aurantiaca Sweet.
H. bulbifera
H. collina Vent. (Cape yellow tulip)
H. elegans Sweet.
H. Lucassii L. Bolus
Homeria pallida Baker (Transvaal yellow tulip)
H. pura N.E. Br. (Yellow tulip)
Moraea polyanthus Thunb. (Blue tulip ; Cape tulip)
M. spathacea Ker. (Large yellow tulip)
M. tenuis

Gunn, of the University of Cape Town, isolated digitalin-like active principles from some species of *Homeria*. The symptoms and post mortem appearances seen in tulip poisoning are indistinguishable from those caused by *Urginea burkei*.

E. CRASSULACEAE

Species of Cotyledon

The undermentioned species of *Cotyledon* (" Krimpsiektebossies ", " Nentabossies ") cause a disease known as " krimpsiekte " (spasm disease) or " Nenta ", and are prevalent in the more arid regions of South Africa.

C. cacalioides L.f.
C. decussata Sims
C. Ecklonіana Harv.
C. leucophylla C.A. Sm.
C. fascicularis Ait.
C. reticulata Thunb.
C. ventricosa Burm.

The disease is most common among goats, as the areas in which the above plants occur are more suitable for goat farming than for sheep farming. Some species

of *Cotyledon* are more inclined than others to cause " opblaas-krimpsiekte " (hoven and spasms). Clonic spasms (shivering) are as a rule followed by paralysis. In some cases, torticollis supervenes for months. The driving of flocks which have grazed on pastures where *Cotyledon* occurs precipitates the symptoms and aggravates the disease. At Onderstepoort, Kamerman isolated the poisonous principle, cotyledon-toxin, from different species of *Cotyledon*.

F. LEGUMINOSAE

(1) Crotalaria Burkeana Benth.

Ingestion of the plant (" stywesiekte-bossie ", " klappers ", stiff-sickness bush or rattlebush) causes an acute inflammation of the laminae of the hoofs of cattle, donkeys and sheep, In the course of time, the inflammation becomes chronic and the hoofs grow out to enormous lengths, as can be seen in the accompanying photograph. In horses the plant sometimes causes an acute parenchymatous hepatitis (inflammation of the liver) and gastro-enteritis. Its active ingredient is unknown.

(2) Crotalaria dura Wood and Evans

The plant (" jaagsiektebossie ", " wilde lusern ", wild lucerne) induces a disease in horses termed " jaagsiekte ", which means that the animals show laboured breathing. Dyspnoea is due to a chronic inflammation of the lungs caused by the ingestion of the plant. The animals may also develop a parenchymatous hepatitis followed by cirrhosis of the liver. The disease has also been produced experimentally by feeding the plant to sheep. Symptoms appear only from about three weeks to a few months after feeding the plant. The active principle is unknown.

G. RUBIACEAE

Pachystigma pygmaeum Robyns (= Vangueria pygmaea Schltr.)

This plant (" gousiektebossie " = quick disease bush) is a heart poison and causes sudden death in stock, especially sheep, goats and cattle (" gousiekte " = quick disease). The plant induces a chronic inflammation of the heart muscle; as soon as affected animals exert themselves, they virtually drop dead. As in *Crotalaria dura* poisoning, this plant has a latent period in that animals die only from about eighteen days to two months after eating the plant.

H. HYDROCYANIC ACID POISONING (" GEILSIEKTE ") ON GRASS PASTURES

During periods of abnormal climatic conditions (showers of rain followed by periods of drought and heat), toxic quantities of hydrocyanic acid occur in many grasses prevalent on South African pastures. Frosted grasses may also develop toxic amounts of this poison. The younger the grass and the more rapid its growth, the more likely is it to develop quantities of hydrocyanic acid sufficient to cause death in stock. Of all the grasses, the different species of *Cynodon* cause the most losses.

The disease caused by eating wilted and frosted grasses is generally termed " geilsiekte " (hydrocyanic acid poisoning) by stock farmers.

The following are the most important members of the Gramineae which may contain toxic quantities of hydrocyanic acid under abnormal climatic conditions :—

Anthephora pubescens Nees.
Aristida congesta R. and S. (" steekgras ")
A. uniplumis Licht (,,)
Eustachys paspaloides (Vahl) Lanza and Matti (= *Chloris petraea* Thunb. (non Sw.).
Rhaphis montana var. *tremula* (Stapf) Phill.
Cynodon Bradleyi Stent (" kweekgras ", quick grass)
C. dactylon Pers. (" kweekgras ")
C. incompletus Nees (" kweekgras ")
C. transvaalensis Burtt-Davy (" kweekgras ")
Digitaria eriantha Steud.
Pogonarthria squamosa (Licht) Pilger.
Sorghum verticelliflorum Stapf (= *S. halepense* Nees (non Pers)). (Johnson grass)
S. saccharatum Pers.
S. sudanense Stapf (Sudan grass)
S. vulgare Pers (Kaffir corn)
Sporobolus fimbriatus Nees.
Themeda triandra Forsk. (" rooi gras ", red grass)
Zea Mays L. (mealie)

Sodium thiosulphate (" hypo ") injected intravenously is an excellent curative agent in cases of hydrocyanic acid poisoning. Great success has been achieved in the prevention of " geilsiekte " by the feeding to stock of licks containing 5 to 10 per cent of sulphur.

I. PASTURE PLANTS CAUSING PHOTOSENSITIZATION

Tribulus terrestris (devil's thorn, " duwweltjie doring "), a member of the Zygophyllaceae, is an excellent feed, but it may under certain climatic conditions (spasmodic showers followed by periods of drought) cause serious losses in small stock, as it renders the animals extremely photosensitive. Only animals with an unpigmented skin show symptoms of photosensitization.

From time to time, outbreaks of photosensitization have occurred on grass pastures consisting of *Panicum maximum* and other species of *Panicum*. The symptoms are identical in *Tribulus* and *Panicum* photosensitization. The first noticeable symptom is restlessness. The animals seek shade, and scratch and rub their faces and ears against stationary objects (irritation of the skin). This is soon followed by pronounced swelling of the ears, lips, and skin of the face. In most cases, the affected parts of the skin become mummified and the ears and lips may even drop off. Rupture of the eye-balls is not infrequent. Many animals die from starvation, as the jaws become hide-bound, with the result that they cannot eat and drink. Loss of wool is also common and general icterus is almost invariably present. Stock-owners term the disease " geeldikkop " (yellow thick head).

By providing shade for the animals and painting or staining the exposed parts (unwoolled) of the skin (head), the disease can be fairly successfully prevented.

In the course of research into photosensitization at Onderstepoort, Rimington, Quin and Roets found that the accumulation of phylloerythrin (a plant porphyrin derived from chlorophyll) in the blood is the cause of the photosensitization by *Tribulus*. The agent in the plant which causes the general icterus is still unknown.

Fig. 1.

Fig. 2

Fig. 3.

Fig. 4.

Fig. 1. Sheep showing symptoms of "vermeersiekte."
Fig. 2. Mummification of ears, lips and skin of face as a result of photosensitization caused by *Panicum*.
Fig. 3. Kaalsiekte. Kid showing complete loss of hair.
Fig. 4. Kaalsiekte. Skin burnt by sun.

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